THE SCIENTIFIC MONTHLY

OCTOBER, 1938

DEDICATION OF THE FRANKLIN MEMORIAL

IN HONOR OF BENJAMIN FRANKLIN

By Major THOMAS COULSON

THE FRANKLIN INSTITUTE, PHILADELPHIA

BENJAMIN FRANKLIN has been called the "typical American," but it would be more accurate to say that he was the only American whose personality fulfilled all the requirements of the Franklin type. An institution which proudly displays over its main entrance the legend: "In honor of Benjamin Franklin" must display a versatility and achieve a measure of success which will stamp it not only as truly American, but also as worthy of the great American whose name it bears.

No one knows why the Franklin Institute was blessed with that name. One hundred and fourteen years ago, when the Institute was founded, Franklin's memory was not held in high repute. That is not unnatural. His work was too great and too near to be seen in the proper perspective; time was required to permit a full realization of its value. The choice of name which now seems to have been so happy was a remarkable tribute to the foresight of those men who, during the presidency of Monroe, founded a scientific institution and called it "The Franklin Institute of Pennsylvania."

In the first decade of the nineteenth century the possibilities of obtaining a technical education were restricted to youths who were willing to undergo an apprenticeship to a trade. Knowledge was acquired by casual contact with journeymen, in conversation with fellow-workers and by technical operation. If the student wished to progress in his career he had to supplement this empirical knowledge by private and individual study. It was not realized that the scientific theory underlying practice must be taught and studied with understanding before it can be applied to the welfare of mankind.

At the time when the Franklin Institute was founded the industrial revolution was changing the conditions of our national life. There was a great quickening of thought produced by the introduction of machinery to replace hand labor, but the social adjustments necessary to adjust the growing industry to human needs had not been thought of. There were no technical colleges, no high schools; the Mechanics Institute was the sole dispenser of technical education. Unhappily this was only available to those who were indentured to industry.

Largely through the instrumentality of a young man, Samuel Vaughan Merrick, steps were taken to organize an institute which would provide qualified instructors to teach science to anyone who sought instruction, rich or poor, young or old, by night as well as by day,

Photograph by Gladys Muller

"IN HONOR OF BENJAMIN FRANKLIN"

THE NEW BUILDING, VIEWED FROM ACROSS LOGAN SQUARE. THE FLIGHT OF STEPS LEADS DIRECTLY TO THE FRANKLIN MEMORIAL HALL. THIS WAS ONE OF THE LAST GREAT BUILDINGS DESIGNED BY THE LATE JOHN T. WINDRIM, ARCHITECT.

and at a price within every one's reach. It was proposed to found a society of men whose reputation and special knowledge would fit them to investigate claims and to award certificates of merit to those inventors who were worthy of recognition. A modest conception of a museum was outlined. That was the beginning of "The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanics Arts."

How eagerly its early promise was recognized may be seen from the variety of occupations followed by the men who hastened to subscribe their names after the scheme was first advanced. Among the first twenty-one names are those of fire-engine maker (that was Merrick), merchant, brewer, teacher, saddler, plasterer, plumber, marble mason, clothier, shot manufacturer, druggist, counselor and blacksmith. So determined were these enthusiasts to serve the public that their haste to do good was almost unseemly.

The meeting of organization was called for February 5; by March 3 some four hundred and fifty members had enrolled; and by April the first professor of chemistry and mineralogy (Dr. William H. Keating) was delivering his lectures. Later in that year a school of architectural and mechanical drawing was flourishing, and within two years the first

high school was established. It is noteworthy that this high school became the model when the local authorities assumed responsibility for the higher grades of education. As the more liberal studies were provided for under the expanding public school system the institute began to confine itself to the more strictly scientific pursuits envisaged by its founders, and many courses were dropped, but the school for mechanical drawing continued for 99 years.

The lectures given before the institute membership have been continued in unbroken sequence since the foundation. At first they were of a character calculated to be useful to the elementary students. Soon they developed into reports on the progress of science and technology, and for many years these reports have been presented by those actually responsible for the progress. In that manner the institute members have been kept in close touch with the latest developments in science and the useful arts.

However, as the membership is distributed over the entire civilized world these lectures had to be made available through the medium of a printed journal. This was not the object of the founders. At the time when the institute was initiated scientific publications were expensive and hard to obtain. It was to break down just such difficulties that the institute had been formed, and it was determined that the members, students and apprentices should have equal facilities in reading at a reasonable cost. In August, 1825, was issued a prospectus announcing the forthcoming publication of *The Franklin Journal and Mechanics Magazine* under the editorship of Dr. Thomas P. Jones, professor of mechanics in the institute's school. Most of the earlier articles were abstracts or translations of interesting articles published alsewhere, but the publication of original work was soon commenced and has since remained the principal feature.

Dr. Jones displayed a special interest in patents which, in the rapid development of industry, were of increasing importance. Realizing that the official Patent Office publications were incomplete in the absence of the inventor's full claims, he caused to be published in the *Franklin Journal*, or the *Journal of The Franklin Institute*, as it has been called since 1828, an abstract of the specifications and the claims in full of all American patents. Thus the *Journal* is the only available source for reference to specifications *and* claims of patents issued between 1828 and 1842 (inclusive), after which the Patent Office extended its information.

The reason for publishing the *Journal* was likewise the motive for establishing the library of the institute—to make available to members the numerous books issuing from the presses to meet the demands of the quickened interest in the useful arts and their underlying sciences. At first the books and periodicals were stored at the residence of a member, but in 1829 a reading room was opened and quickly furnished with reading matter through the opening of exchange facilities provided by publication of the *Journal*. Through the course of the century of its existence this library has grown and expanded until it embraces a rich collection of 115,000 volumes and 40,000 pamphlets relating to science (excepting medicine) and technology. It possesses an invaluable number of complete "sets" of periodicals. As a research library it is unique in its field. This means that it is to aid in the production of ideas, not in their dissemination. It promotes invention and discovery.

One of the problems uppermost in the minds of the founders was the need felt by inventors for some competent, trustworthy and impartial body on whom they could rely for a judgment upon the usefulness of their inventions and discoveries. From the original board of

BENJAMIN FRANKLIN

THIS SHOWS THE MODEL USED BY THE SCULPTOR, JAMES EARLE FRASER, IN THE PREPARATION OF THE GREAT STATUE OF BENJAMIN FRANKLIN AT THE FRANKLIN INSTITUTE. FROM THIS STATUE WAS DESIGNED THE NEW HALF-CENT POSTAGE STAMP OF THE UNITED STATES.

examiners appointed for this purpose has grown "The Committee on Science and the Arts" which examines and reports on all new machines, inventions and discoveries submitted to their consideration. In its earlier stages this committee acted as a body for providing wise counsel to would-be inventors by informing them of what had previously been accomplished in their various fields, and when any matter that was novel and of value came to their attention they endorsed it with their approval, thus aiding in securing public approval and reward to the inventor.

As the fame of the institute spread it became the custodian of several funds for furnishing medals of recognition to those men who were most prominent in advancing ideas for the improvement of scientific applications to the well-being of mankind, irrespective of country. Best known of these awards is the Franklin Medal for signal and eminent contributions to science. Among the more distinguished recipients of this medal have been Arrhenius, Bragg, Dewar, Edison, Einstein, Lorentz, Marconi, Michelsen, Planck, Rutherford, Thomson and Zeeman. Seven other medals are awarded annually for distinguished services to science, the industrial arts or for perfection of workmanship. An astonishing and impressive list of scientific and industrial giants could be compiled from the recipients of these medals. Among the names are those of Bell, Crookes, the Curies, De Forest, Diesel, Emil Fischer, Henry Ford, Frederick Ives, C. F. Jenkins, Chevalier Jackson, the Lumieres, Ramsey, Rayleigh, Rutherford, E. A. Sperry, Tesla, Elihu Thomson, Vauclain, Welsbach and Orville Wright.

Our contemporary life is studded with exhibitions. Periodically our leading industries break into a rash of exhibitionism, so that they may display in every detail the implication of their products upon our daily life. A hundred years ago, before industrialism had reached its adolescent stage, neither the manufacturer nor the public had realized the impending changes in living conditions involved in the development of processes, methods and machines; there existed no vehicles by which the public might learn how the manufacturer was trying to fill its needs nor by which the producer might inform the consumer of his achievements. Advertising was primitive. Yet, an organization of the nature of the Franklin Institute, directly and deeply concerned with the problems of science and its applications, could not long ignore the necessity for acting as the medium for educating both the manufacturer, the scientist and the buying public in the functions and relations which bound them to the pursuit of a joint end. Casting about for a means of providing a common meeting place for those concerned with the infant industries and the utilization of their products, the institute hit upon the idea, wholly original in those days, of organizing an exhibition.

In the first quarterly report of the Institute one reads: "It is confidently believed that when the products of our industry are collected from the various workshops now dispersed through the city and state, and exhibited together, they will form a collection calculated to excite a gratifying sense of pride . . . and an encouraging hope that under proper regulations, we may soon compete with foreigners in the manufacture of all useful articles." Before the year had ended the institute had organized the first exhibition of American industry and had displayed it proudly in the historic Carpenter's Hall. There had not been a great deal of time between April and October to make all the necessary preparations, but these early members were fired with a missionary zeal that worked marvels. A strange assortment of goods came from Maine, Rhode Island, Massachusetts, Maryland

THE FRANKLIN INSTITUTE ON SEVENTH STREET
ERECTED IN 1825, THIS OLD BUILDING WAS THE SCENE OF MANY MEMORABLE OCCASIONS DURING THE 108 YEARS THAT IT SERVED AS THE HOME OF THE INSTITUTE. IT STILL STANDS ON SEVENTH STREET, BETWEEN MARKET AND CHESTNUT.

and Ohio in addition to the immediate neighborhood of Philadelphia. There was plenty of variety in the exhibits, too, for medals were awarded for blister steel and grass bonnets, japanned goods and broadcloths, bar iron and carpets, among other more or less useful articles.

Much was learned from this exhibition, and the results were so encouraging that it was resolved to make the exhibition an annual feature of the institute's work. Later they became biennial, and subsequently they were held at irregular intervals, not because the institute was losing its interest in industry, but because the various industries were learning to stand upon their own legs, and specialized exhibitions were necessary to display the rich assortment of goods pouring from the nation's factories.

Before leaving the subject of these exhibitions a word must be said of one or two in particular. That of 1840 was notable for the fine display of Daguerreotypes, then an entertaining novelty. The fiftieth anniversary of the founding of the institute (1874) was celebrated by an unusually successful exhibition in which 268,000 visitors inspected the products of 1,200 exhibitors. A notable contribution to the joy of life was the introduction at this exhibition of the ice-cream soda, given to the world for the first time on this occasion. Great as was the popularity of this exhibition it was completely eclipsed in brilliancy and in value from both the educational

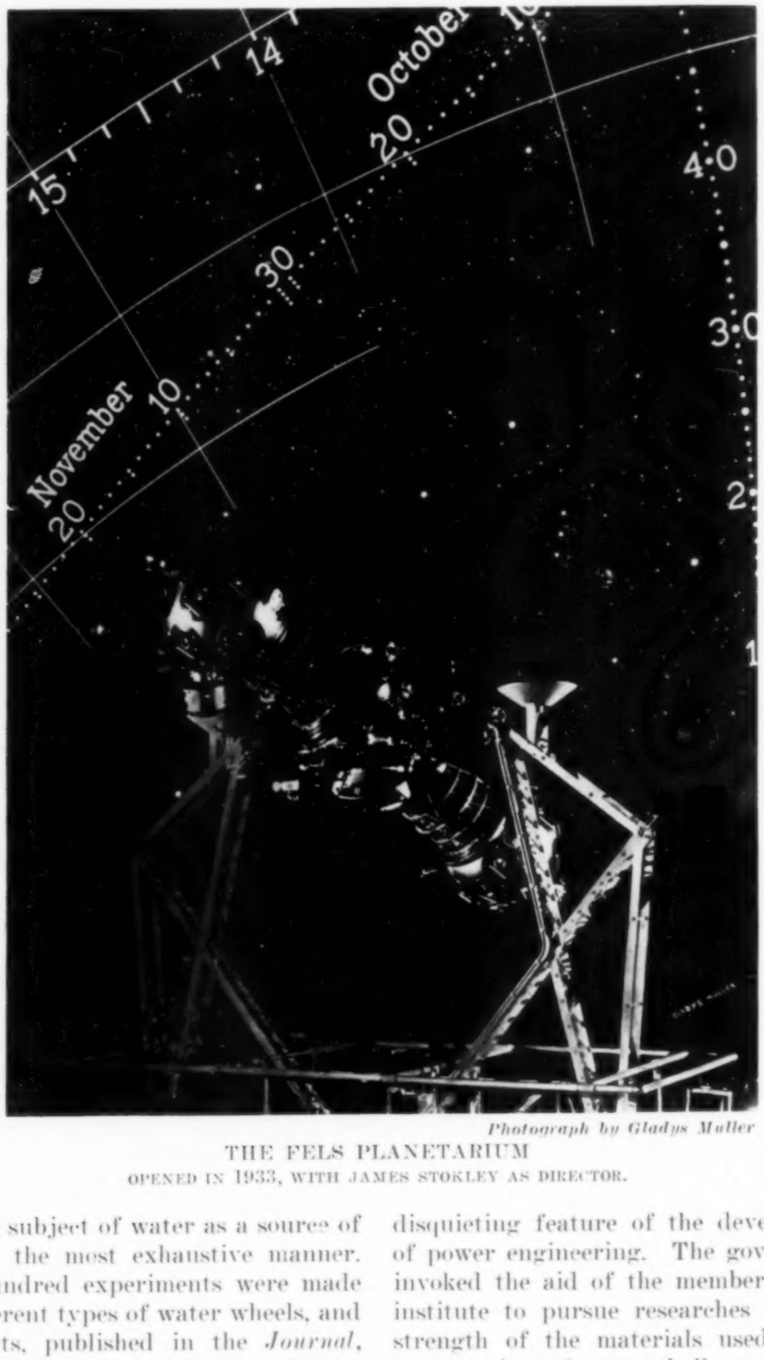
and technical aspects by the Electrical Exhibition of 1884, which was made international in character. This, the first electrical exhibition in this country, was conducted without any financial aid to the institute. It will be understood readily that fifty years ago the exhibitors from the electrical industry were restricted in number, but they lacked nothing in enthusiasm, which was communicated to the visitors, over 299,000 of whom examined the goods displayed. Men of such eminence in the electrical field as Lord Kelvin, Sir Oliver Lodge, Alexander Graham Bell, S. P. Langley, Elihu Thomson, E. J. Houston, Thomas A. Edison and Sir James Dewar were among the interested spectators or exhibitors.

At the present time the institute adopts a different policy in regard to exhibitions. Instead of organizing large displays occasionally, there is a continuously changing exhibition of the products of industry and invention in the spacious museum, of which we shall have more to say.

Once the Franklin Institute had passed through the first few years of feverish activity it barely had time to catch its breath before it was urged to undertake research and investigations at the request of federal, state and local authorities. It seems strange to think that so many of the functions of government departments were farmed out to this body of enthusiastic amateurs, who alone were qualified to discharge them. However, before the value of its labors had been recognized by the authorities the various committees of the institute had proved their worth. They had investi-

THE LECTURE HALL

IN THE OLD FRANKLIN INSTITUTE BUILDING. MANY IMPORTANT DISCOVERIES WERE ANNOUNCED OR DEMONSTRATED FOR THE FIRST TIME IN THIS ROOM.



Photograph by Gladys Muller

THE FELS PLANETARIUM

OPENED IN 1933, WITH JAMES STOKLEY AS DIRECTOR.

gated the subject of water as a source of power in the most exhaustive manner. Seven hundred experiments were made with different types of water wheels, and the results, published in the *Journal*, were of the greatest value to engineers. The frequency of steam boiler explosions, especially on steamboats, was a disquieting feature of the development of power engineering. The government invoked the aid of the members of the institute to pursue researches into the strength of the materials used in the construction of steam boilers. One of the by-products of this investigation was the design and construction of the mech-

anism for testing materials, a pioneer move in the direction of the Bureau of Standards which was so strongly advocated by the institute. Another and more direct step toward proper standardization was the establishment through the institute of uniform sizes of screw threads. The institute's recommendations were adopted by the Federal Government in 1865.

Long before the establishment of systematic weather observation by the State Weather Bureau in 1887, the institute had been laying the foundation for a better study of meteorology for the aid of agriculture. A bill which was presented to the State Legislature in 1833 relating to weights and measures was forwarded to the institute for examination and report. As a result the recommendations submitted were adopted and form the basis of the present laws on the matter.

The city of Philadelphia has made frequent reference to the experts of the institute for guidance upon many of its problems. Important studies of highway paving, protection from lightning, prevention of fires in theaters, river pollution and water supply were conducted and formed the basis for the city's manner of regulating these problems.

It is obvious from this record of service to science, industry and the community at large that the Franklin Institute was first to recognize a great many of the implications arising from the development of human progress and to suggest how technical development might be adjusted to the community's needs. As industry grew stronger and became independent of outside aid the institute withdrew from the necessity of educating the consumer to industrial advances. As the public school system grew aware of its responsibility to youth and began to bear an increasing share of the burden of education, the institute relinquished this task to the local education authorities. But it is equally obvious that such a virile organization could not surrender its activity and sink into a stage of moribundity. No sooner were its services to the community curtailed in one direction than the members sought for new means of adopting themselves to the changed conditions of life, and they cast about for the best method of supplementing the school system's instruction. The fortunate acquisition of the services of Dr. Howard McClenahan as secretary of the institute brought to its work a penetrating mind and a directional zeal that was unsurpassed. One of Dr. McClenahan's first conceptions was the creation of a dynamic museum upon a scale hitherto unattempted in this country.

Finding in the Poor Richard Club a body of men devoted to the perpetuation of Franklin's mental attitudes the happy idea was conceived of uniting their forces to those of the institute for the erection of a memorial to Franklin that would embrace all or most of his manifold interests, and to translate them into terms of contemporary life. The final achievement excelled the visions of the creators. The intention of the institute was to establish a technological museum; the Poor Richard Club wanted to erect a monument to Benjamin Franklin. Why not unite the two? Under the inspired leadership of Dr. McClenahan and that of Cyrus Curtis (the great Philadelphia publisher whose *Saturday Evening Post* descended directly from Franklin's *Pennsylvania Gazette*) a mammoth impulse was given to the movement. When subscriptions were asked it needed but twelve days to produce $5,000,000, besides innumerable contributions of material suitable for exhibition in the projected museum.

In Europe a new interpretation had been placed upon the work of the museum. The newer conception saw it as a place where the ordinary man is placed upon an equal footing with the trained student, he is admitted to the wonder-

BUILDING OF THE BARTOL RESEARCH FOUNDATION

RESEARCH IN FUNDAMENTAL PHYSICS IS CARRIED ON BY THE INSTITUTE IN THIS BUILDING AT SWARTHMORE, PA. THE WATER TOWER HAS RECENTLY BEEN ERECTED FOR THE INVESTIGATION OF THE ABSORPTION OF COSMIC RAYS CARRIED ON BY DR. W. F. G. SWANN, DIRECTOR OF THE FOUNDATION.

land of science, and becomes a free citizen in that vast territory of industrial operation whose boundaries had been closed to him by ignorance. Here the layman entered the magic world of scientific and engineering accomplishment, and through the same agency the scientist, the inventor and the manufacturer approached the community which they had to serve. The labor of man the creator was passed through the crucible of the trained mind and interpreted so that the lay mind might comprehend. The new Franklin Institute Museum bore that new conception to America and speedily translated it into reality.

The new museum achieved instant popularity. The visitors came, not to marvel, but to *use* the exhibits. Therein lay the secret to the departure from conventional museum practice. The Franklin Institute Museum was designed for utility. As the memorial to Benjamin Franklin it had to follow his type of mind. Franklin is frequently spoken of as a philosopher, but we must never picture him as a mere metaphysical speculator. He was far from that. Indeed, there is no one in the whole realm of philosophy with a more simple, practical turn of mind. "What signifies philosophy," he asked in one of his letters, "that does not apply to some use?" Therefore, utility became the keynote of this museum.

Now, the genius of the American people is mechanical rather than theoretical. For this reason its interest lies in the results of science rather than in science itself, but an abounding curiosity makes the average American keenly interested in underlying principles of science if they are brought within his grasp. Few scientific principles are comprehensible without laboratory proof requiring skilful manipulation of apparatus, delicate instruments and an ability for careful measuring beyond the lay-

man's reach. The purpose of this museum was to provide the simple citizen with a personal laboratory in which a complicated scientific theory or mechanical problem would work itself out before his eyes with uncanny precision and without special effort on his part. Special apparatus was designed to perform the functions of the experimenter by automatic impulse. All that the curious visitor has to do is to push an electric button to set the mechanism in operation.

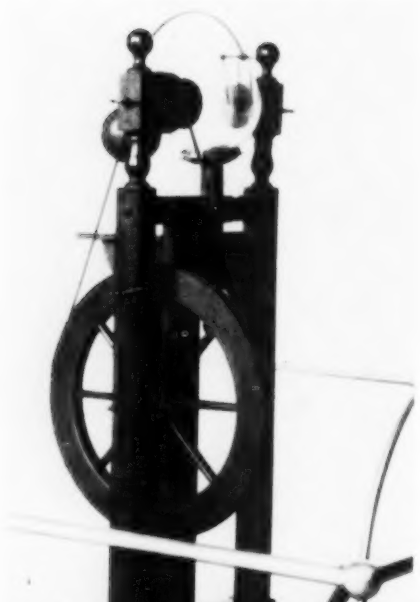
Fortunately, the institute was well served by the staff selected to design its exhibits. Dr. James Barnes in the physics section, Charles E. Bonine in the sections of engineering and transportation, Dr. Nicol H. Smith in chemistry, Russell L. Davis in the field of graphic arts, C. Townsend Ludington in aviation and James Stokley in astronomy, were all admirably qualified for translating the technical features of their subjects into automatic expression. Theirs was not merely the problem of designing apparatus. While a chemist or a physicist prides himself upon the delicacy of his experimental apparatus, that which had to be employed by thousands of visitors must, of necessity, be a sturdy and serviceable structure able to withstand abuse.

Astronomy is happily treated in two ways. On the roof of the museum is the largest and finest public observatory in the country. Two fine telescopes, a 24-inch reflecting and a 14-inch refracting instrument, are available to visitors whenever the weather is favorable for observation. Although the observatory is enriched with numerous other instruments of historical and practical aid in the study of astronomy, visitors have the opportunity of pursuing their studies in all weathers in the Fels Planetarium, where a wide variety of natural phenomena can be faithfully produced indoors. Because this wonderful instrument is capable of reproducing the skies as they are visible from any place and at any time it has been possible to take a broad view of astronomy by changing the demonstrations each month. The ingenuity of the staff has been severely taxed in designing apparatus for producing realistic illustrations of eclipses, meteors, aurora, etc., not provided by the standard instrument, but, so far, they have surmounted their problems with remarkable success.

The subject of graphic arts, because of its importance in the life of Benjamin Franklin, has naturally assumed a relatively wide appeal in its treatment. The whole subject is treated thoroughly in actual practice. Beginning with a magnificent model paper-making machine, which shows in detail the manufacture of paper, to the printing of much of the institute's requirements in this direction, and the trimming of the finished product, the visitor has full opportunity to examine the various processes and methods of printing, illustration and reproduction of the fine arts. Historically, this section is highly enriched with personal mementoes of Benjamin Franklin and a completely furnished colonial printing shop.

The chemistry section is a sheer joy to the schoolboy and the more mature visitor alike. Exhibits are marvelously designed to illustrate the fundamentals of chemical science by experiment, and to show how they are employed by the industrial chemist to give us better and cheaper products for our use and happiness. Articles of beauty rather than utility, such as glittering glass and the more delightful products of the dye bath, have been artfully introduced to make this department a place of enchantment to the visitor whose idea of chemistry is based upon the inadequate and often painful recollections of incomplete high-school studies.

Because the industrial chemical plants are performing frequent minor revolutions in our contemporary living condi-



Photograph by Gladys Muller
BENJAMIN FRANKLIN'S ELECTRICAL MACHINE
THIS FAMOUS MACHINE WAS USED BY FRANKLIN IN HIS EXPERIMENTS ON ELECTRICITY, 1747–1753. IT WAS PRESENTED TO THE INSTITUTE IN OCTOBER, 1826, BY MR. J. REDMAN COXE. FROM MEASUREMENTS OF THIS MACHINE A NUMBER OF REPLICAS HAVE BEEN MADE.

tions, furnishing more stable, cheaper and enduring substitutes for natural products this section offers the best illustration of the museum's striving toward completeness. The section has its fundamental background of chemical reactions, processes and materials which remain substantially unchanged so that the visitor may have a better comprehension of the quickly changed exhibits showing the advances in industrial chemistry. Changes of exhibits in this respect are frequent and of such an elaborate nature that one sees instantly how the industrialist has recognized the intrinsic value of the museum as an agency for educating the consuming public to the advantages it derives from the transformation of substances, often of little value in themselves, into products of real value. For a large proportion of these beautiful displays, placed only on temporary exhibition in different parts of the museum, are provided by industrial firms.

Like the chemistry section that devoted to physics is concerned with providing simple demonstrations of the fundamental laws of nature. This, too, reflects a happy combination of profound knowledge and the ability to interpret it to the layman. Here is an astonish-

Photograph by Gladys Muller
COLD LIGHT EXPERIMENT
AS GIVEN BY A DEMONSTRATOR ON ONE OF THE FRANKLIN INSTITUTE'S TRAVELING SHOWS.

Photograph by Gladys Muller

PUSH BUTTON SCIENCE

A TYPICAL EXAMPLE OF THE MEANS ADOPTED FOR SHOWING DIFFICULT PROCESSES THROUGH SELF-OPERATED ACTION EXHIBITS. THIS ONE SHOWS THE RECOVERY OF CHLORINE AND CAUSTIC SODA FROM SALT. THE STORY IS TOLD BY A SPOKEN DESCRIPTION REPRODUCED BY PHONOGRAPH.

ing array of working experiments illustrating the principles underlying the vast collection of practical applications that has been assembled by several other departments.

Land transportation from the Conestoga wagon to the latest model of automobile; marine transportation from John Fitch's first American steamship to the bridge of a modern liner; electrical communication by radio, telegraph and telephone; and illuminating engineering from rush-light to white light by fluorescence, show the variety of physical application brought forth by the forward sweep of civilization.

The aviation section may be quoted as illustrating the successful blend of history and modern practice which characterizes this modern form of education by museum exhibits. Here the visitor can study at leisure the theory of "lift" and resistance in a number of prepared experiments involving the use of wind-tunnels. He can turn from this theory to its application in the original applications by Orville and Wilbur Wright as shown in their thirteenth airplane; in a historic machine—that which Amelia Earhart flew across the Atlantic; in a recent example of rotating wings as employed in an auto-gyro; and, finally, he may climb into a training machine and observe in detail how the pilot controls his flight.

Startling contrasts abound. The visitor moves away from a giant locomotive (which he may actually drive!) to the smallest operating steam engine in existence; from Franklin's own friction machine to a device which enables the visitor to hear his own voice over the telephone; from examples of misspent enthusiasm devoted to the perfection of a perpetual motion machine to instruments that detect earthquakes in the far Pacific.

This new conception of a museum is one of the most dynamic forces in education, primary or adult, that the mind of man has yet conceived. It is a scientific playground with a serious object. Its ageless appeal assures its popularity exactly as wise old Benjamin Franklin himself would have wished. How that wonderful old man would have enjoyed it!

The Franklin Institute does not restrict its energies to the education of the layman or to the dissemination of ideas

HOWARD McCLENAHAN, 1872–1935
SECRETARY AND DIRECTOR OF THE FRANKLIN INSTITUTE AND EDITOR OF ITS JOURNAL UNTIL HIS DEATH. UNTIL HIS ELECTION TO THIS POSITION IN 1925, DR. McCLENAHAN WAS PROFESSOR OF PHYSICS AND DEAN OF THE COLLEGE AT PRINCETON UNIVERSITY.

through the instrumentality of its lectures. In two separate directions it engages in pure research. The Bartol Research Foundation, directed by Dr. W. F. G. Swann, and the Biochemical Research Foundation, under Dr. Ellice McDonald, are constantly making additions to knowledge, the former in physics and the latter in biochemistry.

It was a matter of more than general regret that Dr. McClenahan did not live to see the completion of his original conception, but he has been ably succeeded by Dr. Henry Butler Allen, under whose direction two important features have been brought to fruition. It was felt that, while the museum admirably answered the purpose of educating those who could come to observe its wonders, the work was incomplete until some provision had been made to reach those who were unable to pay frequent visits to Philadelphia in order to keep pace with the many changes in the museum's exhibitions.

Accordingly, Dr. Allen promoted the idea of designing traveling shows which could be carried anywhere, each performance demonstrating with the aid of numerous action exhibits certain phases of modern science. Two such traveling shows have already established the fact that the effort meets an acute want. The first deals with chemistry, and the second with aviation in a manner that delights an audience.

It is, thus, a well-rounded program that the institute has undertaken and pursued through more than a century. Its culmination as a memorial to Benjamin Franklin was recently celebrated in brilliant ceremonies extending over three days which marked the unveiling of a handsome statue of Franklin. These ceremonies were attended by scholars from all parts, come to pay tribute to America's first scientist in the

Photograph by Gladys Muller
HENRY BUTLER ALLEN
SECRETARY AND DIRECTOR OF THE FRANKLIN INSTITUTE.

name of the learned societies and colleges which had honored him in life.

America owes a lasting debt of gratitude to this man who did so many things for the advancement of mankind and more particularly for the advancement of that little group of colonies in America which gave him being and which he loved with such devotion. That debt is paid in part most effectively, we believe, and in a manner which would have gratified the creditor by the erection and maintenance of this superb museum. If Franklin could see what has been done in his name and for his memory, the kindly heart would be moved, the high sense of social duty would be satisfied, by the spectacle of well-earned wealth, neither squandered in tawdry luxury nor vainglorious show, nor scattered with the careless charity which blesses neither him that gives nor him that takes, but expended in a well-considered plan for the aid of present and future generations of those who are willing to help themselves.

INFLUENCE OF ASTRONOMY ON SCIENCE[1]

By Dr. F. R. MOULTON

PERMANENT SECRETARY, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Many arts and sciences have contributed to the exploration of the celestial regions. Reciprocally the heavens have illuminated and are illuminating many of the sciences that pertain to the earth, for our planet has been found to be only a particle in a universe of matter, its life only an incident in the history of the cosmos, and terrestrial phenomena and laws only particular examples of universal events and principles.

What is the foundation on which all science rests? It is what we think of as the orderliness of the universe, the regularities in the sequences of its phenomena. Without orderliness there could be no science, for unless there were a firm conviction that nature is orderly there would be no attempt to discover its order. In this age of science it is difficult to realize that in ancient times men almost universally believed that the physical universe is subject to the whims of capricious gods and goddesses. Then chaos prevailed on the earth and in the heavens above; superstitions cast their terrifying shadows over mankind. But before the dawn of recorded history regularities in such phenomena as the recurring seasons and the phases of the moon had been noted. Even before the time of Aristotle, in the fourth century B.C., the lengths of the month and the year had been measured to within a minute or two, the inclination of the plane of the earth's equator to the plane of its orbit had been determined with considerable accuracy, the causes of eclipses of the sun and of the moon had been discovered, and much progress had been made in developing theories of cycles and epicycles for explaining the apparent motions of the sun, the moon and the planets among the stars. All these great results, depending upon centuries of observations, had been established before any considerable steps had been taken in the development of the sciences that pertain only to things on the earth. It is to the glory of astronomy that in it men thus first perceived that the universe is orderly and entered on the pathway to science.

It may be surprising that order should have been first clearly perceived in phenomena presented by distant things. But distance smooths to imperceptibility the countless little ripples of phenomena which would confuse us with their complexities were we among them, and leaves

[1] Address at the dedication of the Franklin Memorial, May 20, 1938.

to our perceptions only the regularly recurring great waves which roll along like the swells of the ocean. Though the moon has more than a thousand measurable cycles in its motion, a few determine all the important characteristics in the succession of its phases. In ever-changing shape, it courses through the night sky when all the distractions of the day are covered by darkness. Inaccessible and somewhat mysterious and with cycles of change short enough to be held easily in the memory, it attracts the attention and makes clear the orderly succession of its phenomena.

One of the principal methods in the development of science is generalization. If the motions of the moon are orderly, then why not the motions of those mysterious wanderers among the stars, the planets? Thus the ancients must have asked themselves the question. Since the planets revolve around the sun instead of around the earth, their apparent motions as observed from this rotating and revolving planet are enormously more complex than those of the moon. Yet long series of observations and endless calculations had led to the discovery of the order in them by the beginning of our era. All who have read the Almagest of Claudius Ptolemy, which was published about 1,800 years ago, have been amazed at his knowledge of the apparent motions of the planets and at the perfection of his theories for explaining them. In only a few other sciences have similar very close correspondences between theories and observed phenomena been reached even at the present day.

The words "order" and "orderliness" have been used as though they have perfectly definite meanings which are generally understood. But we find on examination that it is difficult if not impossible to define them and that it is equally difficult to determine whether natural phenomena are orderly according to any definition that we may adopt. It does not relieve us to say that phenomena are orderly when they obey laws that we can state, for essentially "laws of nature" are only descriptions of phenomena, often in time sequences. There is nothing of compulsion or causality in laws of nature, for they are man-made—and often man-destroyed—formulations of how certain classes of things exist or occur. Consequently, if there is any definite content in such a phase as a "law of nature" it belongs to a description, whether in words or symbols, that scientists themselves have invented.

Now what properties of a description entitle us to say that the phenomena it describes are orderly? A ready answer would be that the description is simple. But what is simple depends to a large extent upon the information and experience of the person considering it. It depends also upon the terminology or notation in which it is expressed. For example, the unperturbed motion of the earth around the sun is simple to one familiar with the properties of conic sections, but enormously complicated to one who does not have such knowledge. Or, as to notation, explicit formulas describing the complicated motions of the moon fill many pages, but the differential equations which contain implicitly everything pertaining to its motion may be written on a calling card. Simplicity of a description, therefore, does not appear to be a satisfactory criterion for determining whether the phenomena it describes are orderly, for simplicity depends in considerable part upon considerations that are entirely independent of the things described.

Another possible criterion of orderliness of phenomena is whether or not they are cyclical in character. Most of the phenomena with which we are generally familiar are approximately cyclical. Not only do day and night and the seasons endlessly recur, but there are fundamental rhythms in our own lives—the beatings of our hearts, the inhalations and exhalations of our lungs, our periods of

activity and repose, the electric potentials that rise and fall in our brains. But phenomena do not exactly repeat themselves. No day ever exactly duplicated another day, no two seasons were ever exactly alike. Although strict periodicity in nature is never found, the approximately cyclical character of phenomena appears to have been fundamental in the origin and development of science and to be fundamental for its progress. Indeed, without repetitions our memories would appear to play only with dreams and our reason would grope in vain for materials for its use. That is, the experiences which are basic in the evolution and exercise of our mental processes are cyclical in character. In general, we feel that we understand phenomena only when we analyze them into series of nearly repeating elementary events. When we have succeeded in such an analysis, we regard the phenomena as orderly, and we are satisfied.

Science was born in astronomy because many celestial phenomena are compounded of relatively few cycles. It flourished long in this science before there were comparable developments in other fields both because of the simplicity of its repetitions and because of the amazing successes of its predictions. For many centuries it alone filled the reason, as well as the imagination, with awe.

Throughout the history of science there have been attempts to discover the *causes* of phenomena instead of simply *how* phenomena occur. To account for the motions of the planets the Greeks invented crystalline spheres, apparently not realizing that if they felt impelled to ascribe causes they should explain also both the crystalline spheres and the reason for their rotation. A parallel case was the invention of the luminiferous ether to carry the transverse waves of radiant energy. These fictitious causes or instruments are in the nature of anthropomorphisms, having their origin in our feeling that by acts of our wills we cause phenomena to occur. In very ancient times men were a little more naive, inventing gods and goddesses as the causes of phenomena. Fundamentally the gods and goddesses of antiquity and the crystalline spheres and ethers of more recent times are alike. All have been introduced arbitrarily in order to make the phenomena of the physical world parallel what we regard as the consequences of our own volitions.

Now and then newly discovered facts or phenomena have compelled the abandonment of irrelevant scaffoldings in our science. Perhaps the earliest clear example was Kepler's derivation from observations of the three laws of planetary motion which he announced more than three hundred years ago. The demonstrated elliptical motions of the planets around the sun at variable angular rates made it impossible to retain as realities the fantastic crystalline spheres of the Greeks. And, similarly, the fact that radiant energy has the properties of both waves and particles eliminates the assumption of a luminiferous ether.

It is remarkable that the history of the theories of the motions of the planets has not had a greater influence on later ideas respecting the essential meaning of "laws of nature." Over and over again, even in astronomy, analogues of the crystalline spheres of the Greeks have been introduced in order to have causes of phenomena, although all we know is the relationships among the phenomena themselves.

One of the greatest and most important changes in point of view in science occurred with the acceptance of the heliocentric theory of the solar system. Although Aristarchus of Samos, three hundred years before the Christian era, clearly formulated the theory that the earth rotates and revolves around the sun, and explained by it the seasons and all the apparent motions of the heavenly

bodies, the earth was almost universally believed to be the center of the universe until the time of Copernicus near the middle of the sixteenth century. In spite of his painstaking and convincing comparisons of theory with observations, the heliocentric theory was not generally accepted even by scientists until after the time of Galileo, a century later. Then the solid earth beneath, contrary to accepted common sense, philosophy and theology, suddenly became a spinning particle flying unsupported in the immensity of space. Man found himself removed from his proud position at the center of the universe to the surface of one of its lesser constituents. As vague fears entered his heart that he might not be the principal object of creation, he naturally resented the new and subversive doctrine.

Another reason that the revolution of the earth about the sun was at first difficult to accept was that there was nothing assigned to support it or to cause it to move. This psychological defect in the theory was partly remedied by the discovery of the laws of motion and the law of gravitation, which were regarded as the cause of the motions of the planets and their satellites. Although this cause was a rather intangible set of formulae, it gradually acquired reality in the minds of scientists, as abstract ideas aldays do with increasing familiarity.

With the formulation of the laws of motion and the discovery of the law of gravitation by Newton, physical science closed a long period, extending from the prehistoric days when men first began to perceive that there is order in the motions of the heavenly bodies down through the centuries of painstaking observations to the time when Kepler laboriously worked out his three laws of planetary motion. With the publication of Newton's "Principia" in 1687, physical science entered on a new and glorious period. The transition from the old to the new was sudden, and the completeness of the revolution in point of view has perhaps never been equalled in science or in any other field of human endeavor.

Previous to the work of Newton descriptions of phenomena had been made by means of tables of values or geometrical constructions or kinematical models. All at once something entirely new was introduced, derivatives of the first and the second orders. With all the background of knowledge and experience we have now, it is difficult for us to realize the revolutionary nature of the new concepts and methods. Let us cast out from our minds Newton's work and think of the problem of describing the path of a projectile in a vacuum. From experience we know that at each instant it has a definite distance and altitude; consequently we can make a table for its coordinates. If we desire its components of velocity we can make a similar table. We can make a diagram of its path and mark off on it intervals of time. The table or the diagram is fairly descriptive of the phenomena—in few fields of science do we have more. But the equations of Newton are universal, containing implicitly complete descriptions of all properties of the motion not only at the surface of the earth but at any other place.

Dynamics originated largely in connection with the problem of explaining the motions of the moon and of the planets, though Galileo had previously gone far in his investigations of the motions of falling bodies. Fortunately the masses of the planets are so small relative to the mass of the sun that each of them moves, at least for several revolutions, almost as though the others do not exist. If it were not for this circumstance, there would not have been any simple laws of planetary motion for Kepler to discover. Without Kepler's laws, Newton could not have verified his theories of the laws of motion and of the law of gravitation. Without the work

of Newton or similar work, dynamics would not have been founded and the progress of all science would have been much slower.

Of equal importance in the founding and verifying of the principles of dynamics was the fact that the sun affects the motions of the moon, and the planets interact upon one another; for these perturbations, as they are called, are the consequences of foreign influences which would be most likely to produce unexpected results if any of the laws from which they are derived were erroneous. Newton himself made more verifications of the principles he laid down than have been made even to-day for almost any other law in the whole domain of science. His successors, particularly Lagrange, Laplace and Euler, extended the agreements between theory and observations to thousands. Some of these verifications of theory were of the most involved nature, consisting of a series of consequences, each of which in turn became the cause of other perturbations. For example, the attraction of the sun slightly increases the period of revolution of the moon, the amount depending upon the dimensions and shape of the orbit of the earth. The planets are slowly altering the shape of the orbit of the earth, with the result that the effects of the sun on the orbit of the moon also gradually are changed. Although the cycle of these slight effects are thousands of centuries in length, Laplace worked out all the complicated interactions of forces and obtained theoretical results which were precisely verified by observations.

It was not of much practical importance in everyday matters that Laplace showed that the gravitational interactions of the bodies of the solar system are in harmony, even to many decimals, with the implications of theory. But these amazing demonstrations of the exactness of the law of gravitation were made in the infancy of, or before the birth of, most of the sciences and scientific theories of the present day—a generation before Dalton's founding of the atomic theory of matter, two generations before Wöhler's first synthesis of an organic compound and Faraday's experiments on the relation between electricity and magnetism, three generations before Joule's and Mayer's formulation of the law of the conservation of energy and Darwin's work on the origin of species, more than a century before chemists and physicists first penetrated into the subatomic world or astronomers had made substantial progress in exploring our galaxy of stars. Even to this day there are no more striking illustrations than the motions of the planets and their satellites that the universe is orderly.

The indirect effects of the triumphs of celestial mechanics during the eighteenth century were the important ones. whenever in later times chemists were tempted to despair of explaining chemical processes or geologists were assuming creation and cataclysms or biologists were appealing to mysterious vital forces, there arose always before them the shining example of perfect order and comprehensibility in the motions of the heavenly bodies. Whenever scientists or philosophers were inclined to take a narrow view of the cosmos in space or in time, the limitations they were about to impose were contradicted by the immensities of the celestial spaces and the long cycles in the motions of the planets.

It is universally agreed that evolution is one of the most important concepts in science. In a sense it completes science. As has been stated, the basis on which science rests is the orderliness of the universe, and orderliness is essentially the approximately cyclical character of phenomena. But phenomena are not exactly repeated. For example, the cycles of the moon's motion do not exactly recur, nor do the waves on the sea or the

characteristics of living organisms. Evolution provides for these continual variations; indeed, it depends on them. The departures from cyclical repetitions of phenomena are not discontinuous or relatively large. They are rather in the nature of slight modifications in the cycles that we regard as essential to order. But when variations occur on the whole in one direction over long periods of time, as they may, the changes eventually become very great. So the fundamental basis of science as enlarged and enriched by the principle of evolution provides us with a universe that is orderly in a limited sense and not essentially unchanging.

Although evolution was adumbrated in the writings of the Greek philosophers, it could not take definite scientific form until recent times. It found its first clear expression in astronomy about a century before Darwin published his "Origin of Species." Curiously it appeared independently in three countries; in England in 1750, in a book by Thomas Wright; in Germany, in 1755, in a brilliant volume by Emmanuel Kant; and in France, in 1796, as a chapter in a general survey of astronomy with which Laplace followed the publication of his monumental "Mécanique Céleste." Each of these writers attempted to trace out the evolution of the solar system on the basis of the principles of mechanics.

Of the three theories of planetary evolution, that of Laplace had by far the greatest influence, partly because of the great name of its author, partly because of its relative simplicity and partly because the scientific world was gradually being prepared for such revolutionary ideas. The nebular hypothesis of Laplace, as it was called, gradually became widely accepted in science. It pointed to a long history for the earth and undoubtedly had an important influence in the struggle among geologists over Catastrophism and Uniformitarianism in the early decades of the nineteenth century. It accustomed scientists to thinking of change in long periods of time and thus prepared the way psychologically for the theory of organic evolution. It affected the philosophy of Spencer and its influence extended even to theology. By the beginning of the twentieth it had tinged the thoughts of all the world.

Since all our knowledge of celestial bodies is obtained from the radiant energy we receive from them, astronomers from the time of Galileo have been interested in the properties of light. About 1608 Jan Lippershey used the property of the refraction of light in designing spectacles. Upon hearing of this work, Galileo at once invented the refracting telescope and with it observed craters on the moon, the largest four satellites of Jupiter and spots on the sun. For different reasons each of these discoveries was of great interest and importance. But with increasing telescopic power, difficulties arose because different colors under given conditions are refracted by different amounts. To avoid these defects, telescope makers turned to the use of mirrors until John Dolland, about 1750, discovered how to correct the errors in refraction by using two pieces of glass having approximately compensating properties. Thus about a century before the invention of photography the requirements of astronomy led to the design and construction of achromatic lenses without which good photographs can not be obtained in white light.

One of the properties of light which has come to play a fundamental rôle in recent physical theories is its velocity in vacant space. The fact that light traverses interplanetary spaces with a finite, though very great, velocity was discovered by Römer, in 1675, only sixty-six years after the invention of the telescope. In this day it is difficult to appreciate the rapidity of the development of observational astronomy which led to

this discovery or the profound effect it had upon scientific thought. It does not seriously detract from its importance that the value obtained by Römer for the velocity of light was about 20 per cent. too large. The stimulating effect of the discovery that radiant energy is transmitted at a finite velocity is illustrated by the fact that Laplace attempted, but without success, to determine the velocity of gravitation.

Our familiarity with the numbers used in expressing the properties of radiant energy dulls us to the amazing realities they represent. The highest velocities with which scientists were familiar before the time of Römer were those of projectiles and of sound in the atmosphere, or of the order of a mile in five seconds. But light flashes through space at a speed equal to seven times the distance around the earth in a second. The lengths of its waves are of the order of a fifty thousandth of an inch. The number of its mysteriously transverse vibrations in a second is, in the case of yellow light, greater than the number of seconds in 18,000,000 years. These are the quantities that a world familiar only with such things as the diameter of a hair and the speed of the flight of birds were suddenly asked to accept as realities.

For more than a century astronomers lamented the fact that there is dispersion of light because it impaired the excellence of their telescopes. Then they gradually came to realize with the development and application of the spectroscope that the composite character of light and its easy separability into its different wave-lengths place within their hands an instrument of the most extraordinary value.

Let us sketch briefly the history of the development of the principles of spectrum analysis. In 1666 Newton passed sunlight through a prism and broke it up into its constituent colors, and he recombined them into white light by passing them through a similar prism in reversed position. For more than a century little progress was made in the analysis of light because all experimenters passed it through a small circular opening before it reached the prism, the images of which overlap and impair definition. Finally, in 1802, Wollaston introduced a narrow slit in place of a prism, the images of which are distinct lines. Immediately progress was rapid. By 1817 Fraunhofer had determined 324 characteristic absorption lines in the spectrum of the sun. All that remained was the formulation of the principles of spectrum analysis in order to interpret the meaning of the Fraunhofer lines and to place in the hands of astronomers a new means of investigation of the most extraordinary and unexpected importance. These principles were first approached by Ångstrom, in 1853, and by David Alter, of Freeport, Pa., in 1854; they were completed in their present form by Kirchhoff between 1859 and 1852.

And what of the results obtained by means of the spectroscope? By its use astronomers have determined the chemical constitution of the sun, its temperature, its period of rotation, the velocities of its violent eruptions, its magnetic condition, its distance from the earth, the density of its atmosphere, and have observed its prominences even when it is not eclipsed. For most scientific purposes the spectroscope has brought the sun down to the earth. It has become a physical laboratory in which the principles of spectrum analysis are verified in the flash spectrum at the time of an eclipse, in which temperatures beyond these of terrestrial laboratories are always available, and in which theories of ionization can be verified.

As applied beyond the solar system, the spectroscope enables astronomers to determine the constitution of the stars,

their temperatures, their velocities in the line of sight, often whether they are double and their periods of revolution, the masses and densities of certain of them, in some cases their periods of rotation, their distances, the existence and character of interstellar molecules and the dimensions and the period of rotation of our galaxy.

Far beyond the borders of our galaxy are other galaxies, perhaps a hundred million of them within five hundred million light years, the greatest distance that can be reached at present. By means of the spectroscope astronomers prove directly in many cases that these galaxies are rotating and also measure their velocities of rotation. From what astronomers learn about these foreign galaxies they acquire a much better understanding of our own. There is, however, one phenomenon revealed by the spectroscope in connection with exterior galaxies that was wholly unexpected and has led to the most startling conclusions. I refer to the fact that their spectral lines are displaced toward the red end of the spectrum by amounts that are directly proportional to their distances. Whether the true explanation of these displacements of spectral lines is that they are due to velocities of recession which are greater the greater the distance of the galaxy, as seems reasonable from theory and from experience in our galaxy; or whether the effects are due to gradual diminutions of the quanta of energy in the passage of light through the enormous distances of intergalactic space without changing Planck's constant, it is perhaps too early to decide. In any case, these observed phenomena are raising questions of the most fundamental character. And the applications of the spectroscope to the sun and to the stars in our own galaxy have impelled scientists to speculate on the origin of radiant energy and the condition of matter having a density, in the dwarf stars, twenty thousand times as great as that of water.

It would be inexcusable to close these remarks without referring to Michelson's attempt to measure the velocity of the earth with respect to the ether and his failure to find the expected result, for it led eventually to the theory of relativity and entirely new conceptions respecting the nature of the universe and of science. Moreover, it may be noted that nearly all the tests of the validity of the equations of relativity are astronomical in nature.

In summary, science originated in observations of the heavenly bodies, and its anthropomorphic character was successively weakened by the requirements of astronomical theories. The exterior universe has taught us much about our earth and its sciences, and much even about the workings of our own minds. The universal genius whose memory we honor to-day lived too early to know about most of the things of which I have spoken. But his daring spirit roamed thus widely through and beyond the science of his day, at one time reading the records of ancient life preserved in fossils in the rocks, at another drawing lightning from the clouds, at another finding delight in the wild flowers of the fields, at another turning his eyes and his mind to the stars. As a tribute to him I should like to paraphrase an epitaph which appears over the tomb of Newton in Westminster Abbey, where England has buried her noblest dead. In free translation it is: "Mortals, congratulate yourselves that so great a man has lived for the honor of the human race." Concerning Benjamin Franklin let us say: Americans, let us congratulate ourselves that so great a man has lived for the honor of our country.

VOLCANOES, GEYSERS AND HOT SPRINGS[1]

By Dr. ARTHUR L. DAY

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION

ALTHOUGH volcanoes have been a subject of active inquiry for more than two hundred years and hot springs for perhaps half that time, there is an authoritative volume (Meunier, "Les Convulsions de l'Écorce terrestre") published as late as 1910, which warns us not to confuse volcanic phenomena with "pseudo-volcanic activity" (hot springs, mud volcanoes, etc.). More intensive studies of recent years, to which I invite your attention, seem to prove that all these phenomena are but phases of the same terrestrial activity. The picture may be outlined in this way.

An outbreak of volcanism obviously can occur only in a region where the fluid magma approaches much closer to the surface than in other regions. To raise the question whether structural weakness of the overlying crust or the inherent boring power of magmatic solvents is mainly responsible for the opening is quite immaterial, since both factors doubtless enter into the determination of most volcanic vents. Also whether a lava outpouring takes place along a rift, as in Iceland, or through a well-established central cone, as at Vesuvius, is a question of local physical factors and their distribution. Local temperature, composition and fluidity of the magma and the magnitude of the accumulating pressure below are factors calculated to seek out and determine the point of greatest weakness in the overlying crust. Given a very hot, highly fluid magma, such as the basalt of the Hawaiian volcanoes, and the eruption will usually consist of an explosive release of the accumulated gas pressure at the top of the lava column, followed by a more gradual escape of its volatile content and a quiet outpouring of the lava itself. In other cases where the viscosity of the magma is greater an outbreak will assume a quite different aspect, usually marked by dangerous explosive features. The chief emphasis for our consideration at the moment lies in the fact that the magma itself brings to the surface an immense source of energy which may be released under conditions determined by the amount of this energy, the chemical and physical constitution of the magma and the local resistance of the restraining crust. The fact that these magmatic sources of energy do approach the surface in this way is readily established wherever borings have been made in such regions, for the ground temperature downward rises very rapidly there as compared with other regions where no such approach occurs.

When the magma, highly charged with superheated steam and other gases, approaches close to the surface in this way it is obvious that partial release of its energy at the surface may also take place slowly by gas seepage or chemical attack upon the adjacent rocks as well as through an opening forced through a weak cover.

From this point our consideration leads us to inquire what the composition and physical character of the magma may be at these points of approach to the surface and what consequences may be expected at the surface as a result of this approach.

It is now nearly 200 years since Spallanzani observed that molten lava flowing out upon the surface did not burn on reaching the air and its liquid condition could not be due to burning sulfur or other fuel. He also appears to have been the first to suspect that the magma itself was charged with gaseous material

[1] Address at the dedication of the Franklin Memorial, May 20, 1938.

which accounted for the explosive features and for the porosity of the lava after solidification. He also intimated that its fluidity may have been due to the presence of these volatile materials and that water may have been included among them. It was also frequently noticed by the earlier observers that showers of rain often follow immediately upon volcanic outbreaks, which can be attributed to the condensation of escaping steam.

It is not my purpose to follow through the ramifications and confusion of the controversy which has continued down to the present century regarding the character of this participation of water (*i.e.*, steam) in volcanic outbreaks, a participation which appears always to have been but imperfectly understood and often flatly denied. Indeed as recently as 1911 Brun[2] published an elaborate volume containing analyses of collected volcanic products which purported to show that all volcanic emanations are anhydrous. This misunderstanding was dissipated the following year,[3] when volcanic gases were collected at Kilauea before they could be altered by contact with the air and considerable quantities of water condensed therefrom.

Out of this long controversy we may conclude that water (steam) and other gases which have since been identified are essential ingredients of the magma below ground and participate actively in all the phenomena of volcanism. It remains for us to consider what effect this may have upon the observed surface behavior of volcanoes both at rest and in action.

In the first place it may happen that as the magma approaches the surface and the overlying load diminishes, some separation and concentration of these gaseous ingredients may occur at the top of the rising column of liquid magma. It must follow from this that the solvent action of these concentrated volatiles (water and acid gases) upon the overlying structure must be considerable at these high temperatures (above 1000° C.). Such increased mobility and solvent action must find and follow lines of structural weakness in the overlying crust (faults, joint cracks) and so facilitate the continued rise of the magmatic column and determine its direction. If the stored-up energy (pressure) below is very great rupture and a violent volcanic outbreak may be expected to develop eventually, which may be limited to the partial escape of the compressed and concentrated volatiles (*e.g.*, superheated steam) at the top of a column or may include or be followed by the still highly charged liquid lava itself, as in the case of a bottle of soda water suddenly opened. Such an outbreak of magmatic energy is obviously a volcano.

But, suppose instead of this that the magmatic column approaching the surface encounters porous ground, and the accumulated volatile materials in the upper layers of the column find opportunity for escape by seepage, what then is the result? The chemically active gaseous ingredients (chlorine, fluorine, sulfur) may gradually filter away and expend themselves in reactions in the passages of the overlying rock, enlarging these and perhaps altering the composition of the rock itself, while the superheated steam will continue on until it either escapes or condenses at or near the surface. Both of these activities result in a *gradual* release of the pressure at the top of the magmatic column, perhaps to the extent of preventing an explosive rupture of the restraining crust. Such cases exist and are revealed by the chemical alteration of the rocks, by the chemical content and temperature of the surface springs and by the rapidly increasing ground temperature immediately below the surface. Where rupture

[2] "Recherches sur l'Exhalaison Volcanique," Geneva, 1911.

[3] A. L. Day and E. S. Sherpherd, "Water and Volcanic Activity," *Bull. Geol. Soc. Amer.*, 24: 573, 1913.

has occurred and a volcanic explosion takes place, there is of course abundant and readily available evidence of the activity of the volatile ingredients contained in the magma. When the eruption has subsided and the volcanic conduit is again wholly or partially closed, we must suppose that the release of pressure at the top of the column has stimulated the rise of these volatile materials from greater depths (and higher temperatures) within the liquid mass below and their escape under the ordinary action of gravity. These gases are near the surface now in a zone already perforated and may therefore readily find ways of escape by the slower processes of seepage and filtration until they encounter the cold ground water at the surface. Thereupon magmatic steam will condense, soluble gases (carbon dioxide, chlorine, etc.) will begin to enter solution in the surface water and the fixed gases (hydrogen, nitrogen) will continue on until they escape at the surface.

This ground water has its own circulation above ground, beginning with the rainfall which is distributed by surface runoff and by absorption into the surface layers and openings, and again below ground in seepage and through joint-cracks. Obviously the rainfall in the volcano region will find the ground temperature rapidly increasing as it seeps downward and its penetration will remain shallow and sharply limited wherever the boiling temperature is reached.

If we now suppose that in these regions superheated steam from the magma, more or less associated with the other gaseous products (carbon dioxide, chlorine, sulfur), to be approaching the surface from below and to encounter the surface-water circulation, certain results are immediately obvious. The superheated steam will condense, add its latent and superheat to the surface water and mix with it; other gaseous ingredients will also enter the surface water to greater or less extent, according to their quantities and solubilities, and where these circulating surface waters reappear in springs above ground we may read therein the record of what has occurred. The springs will be hot instead of cold, they will contain carbon dioxide, hydrogen sulfide, chlorine, etc., in proportions appropriate to the solubility of these gases under the prevailing conditions. Or, if the non-condensable gases are in excess, we may find them bubbling through the surface springs themselves and escaping into the air, where they may still be caught and analyzed.

Or again suppose these magmatic emanations happen to rise beneath steep hillslopes, where little or no storage of ground water is found. Then either one of two results will be in evidence: (1) very small springs highly concentrated with the acid ingredients coming from the magma, or (2) the free escape of the magmatic gases, including steam, into the air without previous condensation by ground water. In the first case there result strongly acid springs of small size and turbid, because of the acid attack upon the surrounding ground, in the second the free escape of magmatic gases into the air as roaring fumaroles or steam jets.

Thus we have brought into a single category, now abundantly supported by experimental studies in the field, both the volcano and the hot spring. If the magmatic column rising to the surface carries with it a vast amount of compressed energy the crust may be violently ruptured and an explosive outbreak of both gaseous and liquid ingredients of the magma will inevitably result. When this violent phase has subsided and the major concentration of the more volatile portion of the rising magma near the surface has been discharged, it will almost certainly be followed, throughout the perforated region, by the continuing seepage of the volatile

ingredients which may be traced through the hot springs for hundreds or thousands of years thereafter, or may be interrupted from time to time by more violent phenomena in case the main conduit becomes closed or the accumulation of energy below ground is too rapid to be satisfied by seepage release.

Thus, for example, in the North Island of New Zealand we have a perforated zone running northeast and southwest more than half way across the island. This hot-spring region is of considerable extent and includes at one end, and again near the middle, an active volcano. One of these volcanoes (White Island) rises from the sea beyond the coast line, is more or less continuously active, though only occasionally violent, and a number of hot springs and fumaroles are found there. Some of these are so highly charged with the acid emanations from the magma that the acid concentration in the springs sometimes reaches 10 per cent. It is the highest concentration of volatile magmatic elements which has hitherto been observed.

The other volcano (Tarawera) was violently active in 1886, the explosive activity tearing the mountain wide open from summit to base and opening a rift beyond the base into the hot-spring valley below which extended for a distance of nearly nine miles. Thus we have an intimate association in present time of active volcanism and hot-spring activity in the same area. It also fits in nicely with the above general outline that the hot-spring activity in the rift zone appears to be considerably diminished in volume and intensity since the explosive release of the high concentration of energy in 1886.

On the other hand, we have in the Yellowstone Park a lava plateau of much more ancient date, in which the old centers of volcanic activity are long since closed, but which still shows abundant hot-spring activity throughout its extent of nearly 60 miles north and south. An intensive study of this region, undertaken during the last seven years, has provided a number of the supporting facts in the above analysis. Borings in two different localities revealed, in the region of most abundant surface water supply, a temperature of 180° C. at 406 feet below the surface, in another region, of somewhat less abundant surface water and therefore greater concentration of the products of volcanic emanation, the temperature reached 205° C. within 246 feet of the surface. Steam pressures at the bottom of these bore-holes amounted to 57 and 297 pounds per square inch, respectively. Here also in the course of a chemical study of the hot springs it was found that in the basins, with abundant surface-water supply, the acid concentrations were found to be small, and on the hill-sides, where water was much less abundant, the acid products of volcanic activity were much more highly concentrated.

In discussing the origin, behavior and chemical content of hot springs it is well to bear in mind that a hot spring differs from a cold spring not merely in the fact that it chanced to pass through hot rocks instead of cold ones in coming to the surface. If this were the case the hot springs might be expected to cool rapidly and so presently to become cold themselves, for the rocks conduct heat but poorly. Take a notable example by way of illustration. The spectacular Old Faithful geyser in Yellowstone Park erupts quite regularly, about once an hour, an estimated 10,000 to 12,000 gallons of boiling water and so brings to the surface a nearly uniform quantity of boiling water annually. It is a matter of simple arithmetic to discover that the heat necessary to maintain this intermittent hot spring would require about two square miles of red-hot rock surface, of average heat conductivity, *renewed annually,* merely to heat the water regularly distributed by this geyser. Here it is pertinent to add that none of the hot

water thrown out by Old Faithful returns down the conduit to aid in the next eruption; neither does the extreme cold of winter alter appreciably either the period of its eruptions or the amount of water which is thrown out hourly. We must also reckon with the fact that a dozen other large geysers and some hundreds of smaller hot springs share with Old Faithful the water supply of the Upper Geyser Basin in which it is located.

This leads us, I think, to an inevitable conclusion that the latent heat of more or less superheated steam coming from the magma below, seeping upward through hot ground and condensing upon contact with the circulating ground water near the surface, is the only continuing source of energy which can possibly account for the uniform and continuous supply of heat to great groups of hot springs with a record of activity in their present location, as measured by the amount of sinter deposited upon their domes, of the order of magnitude of at least 10,000 years.

In elaboration of this hypothesis it is noteworthy that in regions of deep ground-water circulation this transfer of heat occurs at greater depth and so under higher pressure and temperature than upon hillsides, where the transfer must take place near the surface where the volume of water and the amount of heat available are both smaller. It is doubtless in consequence of this that neither large hot springs nor geysers are found there.

Further proof is available that hot springs in volcanic regions are heated by condensing steam out of the original magma itself. Surface waters, which circulate by flowing over the rocks or below ground through crevices or joint-cracks, always carry in solution traces of the rock materials through which they have passed. All springs therefore bear a definite record of the kind of rock through which the water has passed because of the soluble ingredients of the rock which are carried in solution. And so it happens that the hot springs of Yellowstone Park carry variable quantities of soluble minerals from the rocks which are readily identifiable by chemical analysis. But they also carry other chemical elements not found in the adjacent rocks, such as sulfur, arsenic, boron, chlorine and fluorine, all of which are characteristic ingredients of volcanic emanations. We have therefore direct proof of the participation of the volcanic gases in hot-spring activity.

The chemical evidence thus fits perfectly into the physical picture which we have built up of the behavior of magma on approaching close to the surface, first in its effects in altering the composition of the rocks into which it intrudes, second, in supplying ingredients to the circulating surface waters (ground waters), which can be traced to no other source, and finally to provide a continuous source of energy over long periods of time for hot springs, geysers and intermittent outbreaks of volcanism.

Up to this point little mention has been made of geysers which form an integral part of our title. The reason for this lies in the fact that the geysers form but a very special case of hot springs and occur only in particular hot-spring regions where certain very exceptional physical conditions are found. In order that we may have a geyser we must have not only a continuing supply of magmatic heat from below, represented by rising superheated steam, as in the case of other hot springs, but also an abundant supply of circulating surface water in which the manner of circulation comes to have very special importance. Geysers can hardly occur without free circulation in underground channels of considerable size as opposed to the slow percolation of ordinary seepage. These channels are probably the outcome of earlier solvent action of the hot water accompanied as before by the more active chemical elements of the emanation. These channels must also

have pockets of such character and distribution that water may enter and steam pressure may accumulate faster than it can escape by seepage. Such pockets or chambers imply a fairly deep-seated circulation compared with other surface waters in the volcano region, and somewhat greater age is indicated than in the case of the more widely distributed quiet hot springs. Both of these conclusions seem to follow from the fact that they must support pressures adequate to discharge considerable columns of water often to heights of several hundred feet. This seems to imply a period of existence sufficient to provide chambers of considerable size and to seal them more or less effectively through deposition of mineral matter from the circulating water itself.

There are but three major geyser regions known in the world to-day. The largest is in the Yellowstone Park, which has already been mentioned; next to it in the number of its geysers is the North Island of New Zealand, and finally the well-known geyser region of Iceland, which, by the way, contains relatively few geysers but hot springs in thousands and several intermittently active volcanoes. The geysers of Iceland were the first to become widely known, and the word "geyser" or "geysir" comes from that country.

The Yellowstone Park in which the geyser phase appears to have reached its highest development is farthest removed in time from any active volcanism. There are glacial boulders from the last ice age scattered over some of the hot-spring formations which may indicate an age of upwards of 50,000 years. In both Iceland and New Zealand, where the number of geysers is much smaller, active volcanism is still closely associated with all the hot-spring activity. This fact may be relevant to the conclusion that time is also necessary for the development of the peculiar local formations in which geysers are built up.

The mechanism of a geyser is not fully understood even to-day, although Bunsen, as early as 1847, offered a theory of the mechanism of the Great Geyser in Iceland which has (somewhat arbitrarily) received general application and acceptance for all geysers since that time. It ought not to be forgotten that Bunsen did not offer it as a general theory of geysers, nor was the Yellowstone Park discovered at the time when Bunsen wrote. Perhaps it is not strange that it does not fit the Yellowstone geysers. Being developed from observations on a single geyser Bunsen's theory appears to-day in the light of available modern data to be precisely what Bunsen intended it to be, namely, a mechanism to account for the Great Geyser only. Its application to the other geysers of the world is not quite justifiable without appropriate adaptation. For example, the Great Geyser of Iceland in Bunsen's time erupted periodically through a large shallow bowl at the surface. With the subsidence of the eruptive feature the accumulation of cooled water in the surface bowl retreated down the tube and disappeared, presumably aiding to condense the compressed steam below and so to end the eruption. In the Yellowstone Park most of the geysers are without this catch basin at the surface and therefore do not return this cooled water to the zone of high steam pressure. According to Bunsen's mechanism, therefore, such geyser eruptions would not stop but would go on in continuous steam jets without intermittent features. It is likewise pertinent to call attention to the fact that Bunsen's theory of the mechanism of the Great Geyser provides for a strictly periodic system, *i.e.*, for eruptions at substantially equal time intervals. With the exception of Old Faithful, to which reference has already been made, few of the Yellowstone geysers exhibit even approximate uniformity in the time interval between eruptions. The Giant, for example, plays at intervals of from two to eighteen days.

Bun-
ory of
ser in
arily)
accep-
e. It
unsen
ry of
Park
unsen
hat it
ysers.
on a
pears
odern
n in-
sm to
Its
f the
t ap-
, the
time
shal-
sub-
e ac-
rface
isap-
ense
end
Park
atch
not
e of
Bun-
yser
l go
ter-
nent
en's
reat
odic
ally
cep-
nce
Yel-
oxi-
val
ex-
to

Perhaps this is not th
time or place for the discu
details, but it is surely suf
from such illustrations th
nism of a geyser, whethe
merely intermittent, is so
intricate than the simple
by Bunsen nearly a centur

It is a matter of some i
ing that many geysers ha
to be permanent features
activity, even during the
present century when t
under closer observation.
which was probably the
to appear in the Yellowsto
the period of historic rec
destroyed its own "plu
violence of its eruptions,
frequently thrown out d
and the violent intermitte
the geyser, which were
the closing years of the la
since given way to a co
hot water. The Imper
in the Yellowstone Parl
though much shorter, h
months). Waimangu
Zealand, which probabl
a greater height (over
any other geyser known
have ended a three-year
activity in 1905, and t
hot spring marks its
These are exceptional
prove anything more t
a concentration of pow
to the rupture of the se

HUMAN HE

When I received an
on this occasion for t
puzzled at first why

[1] Address at the dedic
Memorial, May 20, 1938.

have pockets of such character and distribution that water may enter and steam pressure may accumulate faster than it can escape by seepage. Such pockets or chambers imply a fairly deep-seated circulation compared with other surface waters in the volcano region, and somewhat greater age is indicated than in the case of the more widely distributed quiet hot springs. Both of these conclusions seem to follow from the fact that they must support pressures adequate to discharge considerable columns of water often to heights of several hundred feet. This seems to imply a period of existence sufficient to provide chambers of considerable size and to seal them more or less effectively through deposition of mineral matter from the circulating water itself.

There are but three major geyser regions known in the world to-day. The largest is in the Yellowstone Park, which has already been mentioned; next to it in the number of its geysers is the North Island of New Zealand, and finally the well-known geyser region of Iceland, which, by the way, contains relatively few geysers but hot springs in thousands and several intermittently active volcanoes. The geysers of Iceland were the first to become widely known, and the word "geyser" or "geysir" comes from that country.

The Yellowstone Park in which the geyser phase appears to have reached its highest development is farthest removed in time from any active volcanism. There are glacial boulders from the last ice age scattered over some of the hot-spring formations which may indicate an age of upwards of 50,000 years. In both Iceland and New Zealand, where the number of geysers is much smaller, active volcanism is still closely associated with all the hot-spring activity. This fact may be relevant to the conclusion that time is also necessary for the development of the peculiar local formations in which geysers are built up.

The mechanism of a geyser is not fully understood even to-day, although Bunsen, as early as 1847, offered a theory of the mechanism of the Great Geyser in Iceland which has (somewhat arbitrarily) received general application and acceptance for all geysers since that time. It ought not to be forgotten that Bunsen did not offer it as a general theory of geysers, nor was the Yellowstone Park discovered at the time when Bunsen wrote. Perhaps it is not strange that it does not fit the Yellowstone geysers. Being developed from observations on a single geyser Bunsen's theory appears to-day in the light of available modern data to be precisely what Bunsen intended it to be, namely, a mechanism to account for the Great Geyser only. Its application to the other geysers of the world is not quite justifiable without appropriate adaptation. For example, the Great Geyser of Iceland in Bunsen's time erupted periodically through a large shallow bowl at the surface. With the subsidence of the eruptive feature the accumulation of cooled water in the surface bowl retreated down the tube and disappeared, presumably aiding to condense the compressed steam below and so to end the eruption. In the Yellowstone Park most of the geysers are without this catch basin at the surface and therefore do not return this cooled water to the zone of high steam pressure. According to Bunsen's mechanism, therefore, such geyser eruptions would not stop but would go on in continuous steam jets without intermittent features. It is likewise pertinent to call attention to the fact that Bunsen's theory of the mechanism of the Great Geyser provides for a strictly periodic system, *i.e.*, for eruptions at substantially equal time intervals. With the exception of Old Faithful, to which reference has already been made, few of the Yellowstone geysers exhibit even approximate uniformity in the time interval between eruptions. The Giant, for example, plays at intervals of from two to eighteen days.

Perhaps this is not the appropriate time or place for the discussion of these details, but it is surely sufficiently plain from such illustrations that the mechanism of a geyser, whether periodic or merely intermittent, is somewhat more intricate than the simple one suggested by Bunsen nearly a century ago.

It is a matter of some interest in passing that many geysers have not proved to be permanent features of hot-spring activity, even during the years of this present century when they have been under closer observation. The Excelsior, which was probably the greatest geyser to appear in the Yellowstone Park within the period of historic record, apparently destroyed its own "plumbing" by the violence of its eruptions, for rocks were frequently thrown out during eruptions and the violent intermittent explosions of the geyser, which were characteristic of the closing years of the last century, have since given way to a continuous flow of hot water. The Imperial Geyser, also in the Yellowstone Park, had a similar, though much shorter, history (about 18 months). Waimangu Geyser, in New Zealand, which probably threw water to a greater height (over 1,000 feet) than any other geyser known to us, appears to have ended a three-year period of geyser activity in 1905, and to-day not even a hot spring marks its former location. These are exceptional cases and hardly prove anything more than that too great a concentration of power sometimes leads to the rupture of the sealed chambers and tubes which are necessary to such regulated discharge. As has been stated above, the deposition of silica sinter (geyserite) about some of the geyser openings indicates continuous activity in the same spot for upwards of 10,000 years at the slow rate at which such deposition occurs. Castle, Grotto, White Dome and Old Faithful geysers in Yellowstone Park are illustrations of this.

It is also true that new geysers sometimes appear in these geyser regions and others long dormant return to activity after years of complete subsidence. The New Zealand field contains several notable examples of these long pauses in geyser history (Waikite, Pohutu).

Such a presentation of the volcano-hot-spring problem can provide but the briefest sort of summary of the long campaign of field and laboratory studies extending over more than twenty-five years in time and into several different countries, but it is hoped that the evidence here brought together is sufficiently pertinent and convincing to leave no reasonable doubt that volcanoes and hot springs have a common source of energy, namely, the magma approaching the surface and cooling there, and that the most active agents both in volcanic outbreaks and in hot springs are the more volatile components of the magma which seek to escape as it approaches the surface, and whose subsequent behavior is determined by their composition, by the total energy available, the temperature and the local conditions encountered.

HUMAN HEREDITY AND MODERN GENETICS[1]

By Professor T. H. MORGAN
CALIFORNIA INSTITUTE OF TECHNOLOGY

WHEN I received an invitation to speak on this occasion for the biologists, I was puzzled at first why it was I who was chosen until a friend called my attention to an anecdote told by Franklin:

> Some Madeira wine, that had been bottled in Virginia, had been sent to England. At the opening of one of the bottles three drowned

[1] Address at the dedication of the Franklin Memorial, May 20, 1938.

flies fell out into the first glass that was filled. Having heard it remarked that drowned flies were capable of being revived by the rays of the sun, I proposed making the experiment on these; they were therefore exposed to the sun upon a sieve which had been employed to strain them out of the wine. In less than three hours two of them began by degrees to recover life—they raised themselves upon their legs, wiped their eyes with their forefeet, beat and brushed their wings with their hind feet, and soon after began to fly, finding themselves in Old England without knowing how they came there.

Then, it became clear to me that it was my own interest in flies that suggested to some one that I might be able to explain the resurrection of Franklin's prodigies.

There are several explanations of Franklin's anecdote that have occurred to me—and possibly one that has suggested itself to all of you—But why spoil a good story by explaining it?

Any discussion of human heredity must emphasize the fact that man has a dual form of inheritance, one of which is peculiar to him and absent in all other animals. He inherits not only the physical attributes of his kind, but also, in a different way, the traditions of the race to which he belongs. The child learns partly by imitation, partly by instruction and individual experience, and with the beginning of speech and the invention of writing and printing the inherited racial traditions have come to play an all-important rôle in the later evolution of mankind.

The question then arises whether the habits that have been individually acquired by imitation or training will be impressed on the brain of each individual to become later a part of his physical or shall I say his biological inheritance. This is a very old problem that began with the Greek philosophers. Four hundred years before Christ, the father of medicine, Hippocrates, advocated the view that each part of the body added its contribution to the male element of procreation and thereby transmitted not only the racial characteristics of the male parent but also any additional individual characters acquired by the parent during life. This is the first historical record we have of the theory of the inheritance of acquired characters. Democritus, who lived at about the same time, held a similar view. It is not improbable that such views were widely disseminated in the folklore of still more ancient peoples.

A hundred years later Aristotle discussed the problem pro and con, and on the whole rejected the view that each part of the body contributes something that goes into the make-up of the germinal material, but he seems nevertheless to have accepted the doctrine of the transmission of acquired characters in a more subtle way.

This doctrine persisted throughout the long period between 400 B.C. and 1800, *i.e.*, for 2,200 years, as Zirkle has recently emphasized. It was generally accepted even by the church fathers, and was again brought to the notice of the modern world by the well-known French biologist, Lamarck, in 1806. Later it became a cardinal point in Charles Darwin's theories of evolution, whose hypothesis of pangenesis restated the ancient doctrine of Hippocrates. However, both Lamarck and Darwin made use of the theory in an entirely new way. They both tried to explain on its principles the procedure by which animals become adapted to their environments, and, as a result, they attempted to explain how evolution has taken place.

Seventy years after Lamarck, August Weismann (as had Kant before him) challenged the doctrine of the inheritance of acquired characters in his famous theory of the continuity of the germ plasm. In substance Weismann's theory postulates that the germ cells alone transmit the racial characters and that the germ cells are neither produced by the body cells nor are they affected by the experiences of the individual. Weismann's view is generally accepted to-day.

There still remains the question as to what extent man's physical inheritance lies behind his ability to take advantage of the traditional inheritance of the group to which he belongs, and also by his inventiveness to extend his acquired knowledge into new fields.

~~To put the matter crudely~~: is the mind of the baby a *tabula rasa*—a blank slate on which its racial traditions are to be written; or are there black, white and yellow slates (and perhaps even pink ones)?

The answer is clear. If forefathers had themselves better brains at birth than the average there is a good chance that at least some of the children or descendants may have as good brains. This means that there may be black, white and yellow brains in the sense that one kind may be more inventive or more receptive to one kind of training, and another kind to another kind of training. These qualitative differences may be small, but if they exist at the start the accumulated result of training may be very great.

This leaves out of account the possibility of the occurrence of greatly superior brains, which, so far as we know, may be only the result of happy combinations of all that is best in the race plus favorable opportunities for development; or, such superior brains may be due to the appearance of new types that transcend the original limits. We have no decisive answer to-day, but there is no reason to suppose that the physical evolution of man has come to an end; unless his physical evolution may be retarded or even suppressed by practices arising from his inherited social systems.

May I now turn to more technical problems in the general field of heredity, where the increase in our knowledge since 1900 has been extraordinary, and then consider the problem as to how far we are justified in applying the same principles to the physical education inheritance of man.

(2) ✓ The most outstanding discovery is that of Gregor Mendel in 1865. He formulated two fundamental laws of heredity, the outcome of ten years' work on garden peas. Later the same laws have been found to apply to all other plants and to animals, including man. Second only in importance was the discovery of the mechanism in 1902 by which this kind of inheritance is transmitted from generation to generation. Later still, two additional fundamental laws were discovered that we call the law of linkage and the law of crossing-over. These are also consistent with the working of the same mechanism that accounts for Mendel's laws. A knowledge of these four laws and of the mechanism on which they are based makes it possible to-day to predict exactly what is to be expected when combinations of different characters are brought together by the intercrossing of individuals.

It would take far more time than that allotted to me, were I to attempt to illustrate in detail these principles of heredity; but I may first say a little about the mechanism behind these laws, and then give a few examples to show how the mechanism applies both to human inheritance and to that of other animals.

✓ Each species of animal and plant has in every cell of the body, including the reproductive cells, a definite number of staining bodies called chromosomes. In different species the number ranges from two to over a hundred.

When the reproductive cells reach maturity the number of chromosomes is reduced to half the full number. When the egg is fertilized by a spermatozoon the full number is restored. Hence the characteristic number for each species remains constant. It will be noted that half of the full number has come from the father and half from the mother. The child inherits equally from its father and mother; at least so far as its chromosomes are concerned.

Mendel's first law, the law of segrega-

tion, is explained on the chromosome mechanism in those cases where two contrasted characters (elements) are carried each in one of the members of a pair. This is illustrated by one of Mendel's crosses between tall and short peas. Mendel's second law, the law of independent assortment, applies when two pairs of contrasted characters are carried in different pairs of chromosomes. This is illustrated by Mendel's case of a cross of yellow round and green wrinkled peas; and again by a cross between two color varieties of cattle.

It should be noted that Mendel's second law holds when the two pairs of characters involved are in different chromosome pairs. If this were the whole story there could be only as many types of inheritance as there are unlike chromosomes in each species. Something of the sort is true in general, for we know that the *elements* in a given chromosome tend to be transmitted together.

This is the law of linkage. For example: There are four pairs of chromosomes in Drosophila, and four linkage groups. All the characters in a group *tend* to be inherited together.

But it has also been found that an *orderly* interchange between the two members of homologous chromosomes takes place. This is the law of crossing-over—the breaking up of the linkage groups. A study of the behavior of the chromosomes, at the time when the chromosomes are about to be reduced to the half number, reveals the fact that such an interchange actually takes place. If a fly that has yellow wings and white eyes is crossed to a fly with gray wings and red eyes, then, in the second generation 99 per cent. of the grandchildren are like the grandparents, but 1 per cent. of the grandchildren are cross-overs with red eyes and yellow wings or white eyes and gray wings—they represent 1 per cent. of recombination of the two pairs of characters that went into the cross together.

Due to this kind of interchange it has been possible to discover the actual location of the hereditary elements in the chromosomes which has led to one of the most important developments in the history of chromosomal inheritance. The interchange involves large pieces of the chromosomes rather than individual elements. Two new linkage groups are established that are as permanent as those that preceded them. But these also are subject to interchange again at any level in a new individual in which they come to be present. The result is that in time all possible combinations of characters (elements) are brought about.

Now if crossing-over is as likely to take place at one level as at another in the chromosomes that are interchanging, it follows that the chances of crossing-over between pairs of elements will be greater the farther apart they lie in the linkage group. Conversely, the nearer they are together the less often is crossing-over expected to take place.

On this hypothetical assumption the genes can be arranged in a map. The most complete map is that of the genes of the fruit-fly Drosophila.

This procedure is not as arbitrary as it may seem, for it allows us to predict in what numerical proportion any new gene, that appears as a mutation, will be transmitted in relation to all other known genes.

And now I come to a still more recent discovery, one that, on a factual basis, explains another kind of inheritance. In this case an exchange or translocation may take place between different linkage groups or chromosomes. This discovery was made first from purely genetic evidence and has now been confirmed by a study of the chromosomes in the salivary glands of several species of flies. These glands are present in the larva. Their cells and their contained nuclei are enormously large. Also the chromosomes are large, as seen by comparing the ordinary chromosome group of the fly

with those of the salivary chromosomes, which are nearly 200 times as long.

It was known, from genetic evidence alone, as I have said, that at times a whole piece of one chromosome may become detached and reattached to another chromosome. It was also discovered that a part of one chromosome may be turned around—in reversal of the normal sequence of the genes. Nevertheless, the characters of the fly containing such a translocation or an inversion are in most cases identical with the original fly. This means that the sequence of the genes plays no important rôle in the make-up of a fly if it still retains the full complement of genes. It is true that, in some cases minor changes may be introduced by detachments and reattachments of pieces of chromosomes, but it is a far-fetched argument to assert from this that the theory of the gene is overthrown.

More detailed work has shown a point to point relation between the genes and the bands in the salivary chromosomes. This does not mean necessarily that the bands are the genes, but it shows beyond reasonable doubt that the chromosome maps, built up on the genetic theory of crossing-over (it took twenty-five years to construct these maps) find complete verification in the maps of the salivary chromosomes.

Let me now point to a few cases that illustrate the application of the four fundamental laws of genetics to man.

In man there are blue-eyed and brown-eyed individuals. The children of a mating between blue-eyed and pure brown-eyed individuals have brown eyes. If now two individuals that have had this origin marry their offspring will average 3 brown- to 1 blue-eyed individual. The chromosome mechanism is here the same as that of the garden pea. The inheritance follows Mendel's first law.

The second law may be illustrated by the human blood groups. For several years it has been known that there are four kinds of individuals with respect to the kind of agglutinogens and agglutinins that they contain and that these kinds are inherited in Mendelian fashion (three pairs of allelomorphs). More recently another pair has been found by Landsteiner and Levine that behaves as an independent pair. The combination of this latter with the former will serve to illustrate Mendel's second law.

There is at present one example at least of linkage in man. Haldane has shown that color blindness and haemophilia are characters that are linked in the sex chromosomes. The same evidence shows at least one case of crossing-over between these two pairs of linked genes.

The failure so far to discover more cases of linkage and crossing-over in man is due in part to the presence of 48 pairs of chromosomes and in part to the relatively few simple cases of inheritance in man. What is known, however, suffices to show beyond a reasonable doubt that the four laws of heredity and the mechanism of transmission are the same in man as in other animals.

There is a kind of inheritance in man known as sex-linked inheritance that illustrates beyond a question that the same sex-determining mechanism present in other animals is also present in man. This sex-determining mechanism rests on a difference in the chromosome groups of the male and the female. The female has a pair of X chromosomes; she is XX. The male has one X. Its mate is called the Y chromosome, which is practically empty so far as genes are concerned. He is XY. The ripe egg of the female has one X. There are two kinds of spermatozoa, one with an X, the other with a Y. Any X-bearing sperm fertilizing any egg produces an XX female. Any Y-bearing sperm fertilizing any egg produces an XY male.

Now if one of the X's carries a gene for a certain character, it is found that the inheritance of the character and the distribution of the sex chromosomes run parallel courses. The human pedigree

for haemophilia gives exactly this kind of sex-linked inheritance, and it is now known that the human male has an X and a Y chromosome and that the female has two X's.

Lastly I come to our star case which also brings us back to our starting point: namely, what we owe to nature and what to nurture, to use Galton's terms.

I refer to the occurrence of identical twins. Occasionally two babies are born that in their physical aspects are almost indistinguishable. Sometimes there may be three or four, and the quintuplets, of course. The resemblance lasts throughout life.

There is abundant though indirect evidence that identical twins come from one egg fertilized by one spermatozoon. Hence their physical inheritance is certainly the same. The twins furnish an opportunity to find out to what extent two identical brains will be influenced by the environment in which the training and traditions of the race will come to act on them; especially if the twins are reared apart. Studies of identical twins are now being extensively carried out, and when enough material is collected, and when better tests are found for measuring the intelligence and emotional resemblances and differences shown by such individuals we may hope to get very definite information as to what is owing to heredity and what to environment.

Some one may ask, what has all this to do with Benjamin Franklin? I think both the theory and the facts of modern genetics would have interested him profoundly, because numbers always fascinated him, and modern genetic work is based on precise numerical data. Again, I think he would also have been interested because he was attracted by mechanical devices, and the chromosomes furnish a mechanical explanation of heredity. And lastly I think he would have understood that modern genetics has an important bearing on population problems in which he showed great interest. As our theoretical knowledge of heredity increases, and as its application to the composition of human societies becomes clearer (it is already applied in animal husbandry and in agriculture on a large scale) its significance for the welfare of future society will be more widely appreciated; but the problem is, as I have pointed out, not a single one owing to the dual nature of human inheritance. If the transmission of the traditions of the race, its myths, taboos, customs and even its humanitarian weaknesses come in conflict with the laws of man's physical inheritance the former may at times delay further evolutionary advances of the kind that have brought man to his present status. And, on the other hand, the physical deterioration of the race, that may take place under the abnormal conditions of a complex and protected social life, can be prevented or ameliorated only by an intelligent understanding as to how such physical impairment takes place. The two sides of the problem of human heredity will constitute the future field of human engineering.

IT'S CALLED ELECTRICITY[1]

By Dr. WILLIS R. WHITNEY

VICE-PRESIDENT IN CHARGE OF RESEARCH, GENERAL ELECTRIC COMPANY

It seems regrettable that a man who has spent half a century in close contact with electrical experiments should have to confess ignorance as to just what electricity is!

I have even been told by competent friends that I ought not ask what it is! And yet, I reflect, having in some way

[1] Address at the dedication of the Franklin Memorial, May 21, 1938.

collected a knowledge as to what water is, what copper is and even what faith is, why need I remain so ignorant when it comes to such a common thing as electricity?

I consult history and learn that for centuries of unaltered view-point, electricity was known as a spirit, and because spiritual affinities and human affections were obviously correlated, magnetic powders were prescribed by physicians to increase the attractiveness of unattractive people.

It was not till the days of our own Benjamin Franklin that electricity became one or two kinds of fluid. Fluids seem a little more tangible than spirits, and electricity became quite tangible with Franklin. By simply touching a container he could tell whether or not it was charged with electricity. But with more refined criteria, the fluid idea had to be given up. Electricity acts more like a gas in some cases. Later the gas idea too was inadequate.

The only safe way with electricity is to expect a new picture whenever new tools for better measurement are discovered.

In choosing the title I was guided first by my admiration for Franklin. I am happy in the thought that he was not seriously troubled, as I have been, by not knowing the "why and wherefore" or the quintessence of the things that his experiments taught him. The important point is: he applied what he learned. In many fields he was a most interested and inquisitive investigator, and no one ever enjoyed his occupation more. He simplified observations by pictures, as we do, but, having learned what regularly followed experiment, he encouraged his mind to bring the consequences not only within the range of expectancy but also of utility. This led him, as he wished, into continued productivity. There was no cluttering of his mind with metaphysics or a futile search for primal essences.

I feel sure he read and liked Francis Bacon because Bacon too sought utility so energetically. While Franklin enjoyed his theory of fluid electricity exactly as we do our own pictures of intangibles, he enjoyed no less the experiment through which he materialized the lightning rod.

A more useful reason for my address is interest in youngsters and a feeling that they may be worried, as I have been, by quite harmless scientific bugaboos. I would like to encourage boys to realize the flexibility of electricity. Fortunately, it is difficult to draw a perfect picture of any inside mechanism of nature. Electricity is no exception. Every one who has tried it has had his picture well painted over by later artists. On the other hand, the results of even the simplest experiments remain unaltered, and so constitute the permanent assets. This doesn't mean that pictures are useless. They are valuable catalyzers and are enjoyable. I'd like to encourage and embolden the inquisitiveness of youth. I don't wish to be didactic, but I'd suggest that we are limited in our conceptions by the inadequacy of our words and so can not express the infinite complexity of reality. It is this want which sends our imagination out in search of ideas not yet wordable. This natural, beneficial provision is a wonderful tool, but not an end in itself. Even imperfection of our old words is a boon to science. For example, the moment some one suggests that gases are just a hustling crowd of anything whatever, some interested scientist applies his individual conceptions of "hustling," "crowd" or of "anything whatever" to see if they fit the picture, and then he tries an experiment and learns a new fact. It may be futile to express any essence in words, but it is distinctly useful to try it. Words have in them plenty of inherited characteristics, and, even if perfect for past events, they seldom quite fit the unlim-

ited, novel phenomena of nature. This explains the painfully gradual growth of our scientific vocabulary.

I look on Bacon and Franklin as men who saw the need of gregariousness (I'd even say happy garrulousness) in science. New phenomena which occur constantly must be appreciated, described, perpetuated and used. This means gathering and getting together in more ways than one. So Bacon, about 1600, publicly advised the banding of scientific men to cooperate in research, "For the real and legitimate goal of the Sciences (as Bacon expressed it) is the endowment of human life with new inventions and riches."

Clearly as a consequence of his tireless advocacy, a practical proposal for an institution of experiment was published in England shortly after Bacon's death, and in 1645 well-known scientists modestly undertook inquisitive cooperation, as he had suggested. This group, which developed into the Royal Society of Great Britain in 1661, has been usefully quizzing the unknown ever since.

Thus I connect to the efforts of Bacon that proposal of Franklin's published in 1743 which led to the establishment of the American Philosophical Society. In fact, we read in Franklin's proposal "that a correspondence already begun by some interested members, shall be kept up by this Society with The Royal Society of London," and he offered to act as the first secretary.

I quote also from a letter of Franklin's written 40 years later to Sir Joseph Banks, president of the Royal Society: "Furnished as all Europe now is, with academies of science, with nice instruments and the spirit of experiment, the progress of human knowledge will be rapid and discoveries made of which we at present have no conception. I begin to be almost sorry I was born so soon, since I can not have the happiness of knowing what will be known 100 years hence."

This is not an explanatory review of electricity but an attempt to encourage further questioning and experiment, particularly by youth because the elders are preoccupied. We should let our imaginations work and forget the critics of ideas. In 1747 Franklin wrote to members of the Royal Society explaining his new view of the identity of lightning with electricity—a view that came from his experiments. One of the members of the society read Franklin's conclusions before that august society and reported that "it was laughed at by the connoisseurs." But ten years later the members were glad to elect Franklin to membership.

I am not so much interested in impressing you with Franklin's view of the static electricity in cats' fur and of Jove's thunderbolts, however, as I am in pointing out that his vivid imagination, freely expressed, put lightning rods on buildings. And they are there yet. From noticing the peculiar effectiveness of his knuckle in discharging Leyden jars, his ideas soared into the clouds, so to speak. So he broadcast his new idea, saying, "May not the knowledge of this power of points be of use to mankind in preserving houses, churches, ships, etc., from the stroke of lightning?" Most of us are more conservative and fearful than that. This was no exceptional case with Franklin. His mental flexibility included balloons, and 150 years ago he received the world's first air-mail letter after a balloon carried it across the English channel.

At this point, since I have in mind following some of the lines along which appreciation of electricity has taken place, regardless of electrical quintessences, I confess with Franklin that: "I find a frank acknowledgement of one's ignorance is not only the easiest way to get rid of a difficulty, but the likeliest way to obtain information; and therefore I practice it and think it an honest policy."

I want to be exact in dealing with electricity, but also imaginative, in order to encourage myself and others. Concep-

tions of electricity will continually change by expanding, as they have always done. Indeed, expansion is a most marked property of electricity. Even the smallest trace of it, an electron, may exert influence anywhere. The motion of a speck of electricity in San Francisco is felt in New York, whether it goes by wire or wireless.

Some time ago I reflected that if electricity is anything tangible or like a liquid, it should be possible to put some of it onto a rubber balloon, and, by having the same kind on two balloons, show the repellent forces of similar charges and the attraction of unlike electricities.

I connected two metal plates, charged respectively positive and negative, to a source of 200,000 volts d.c. After making repeated contacts between the plates and the balloons, I was satisfied that balloons could never be charged that way. But I explained my difficulties to Dr. Coolidge, and in a short time he succeeded. He charged the balloons by rubbing them on his hair. Thereafter, but not before, I could easily explain this solution by visualizing conducting films of moisture put onto the otherwise dry balloon from the hair which in turn conducted so-called frictional electricity over the surface. The balloon experiment illustrates a simple, unexpected and encouraging use of the head. The ancient experiment seemed a sort of clincher for the assumption that, whatever electricity really is, there are two and only two kinds, equal and opposite. Franklin called them positive and negative. But negative electricity sometimes acts much more positively than does positive. A radio tube would be quite a different thing if this were not the case. Attempts have been made to represent all the facts by accepting one kind of electricity only. I have always wished that could be arranged. Electricity would then be but one thing. Ordinary so-called neutral matter might be arrangements of that thing, electricity, with or without anything else. The absence of the thing from matter would leave us something new, or, possibly, nothing at all.

One of the beautiful things about electricity is that experiments forever show new and unexpected things. Before the discovery that the smallest bit of electricity is a negative electron, the professor, explaining a carbon arc lamp at school, had different ideas. A very highly magnified image of the arc left us with the impression that the current across the gap between the arc-terminals consisted of positively charged particles. Later I once tried to prove this by measuring the loss of weight of different kinds of arc-terminals. These losses were enormously influenced by position in space, because electrode-burning also took place. If any positive carbon crossed the arc gap, I failed to prove it. Experiments were tried using inert gases and vacuum. There one electrode often lost weight while another gained. But this was apparently due to simple sublimation.

I passed electricity across gaps between gold, platinum and other electrodes and even submerged them in water, hoping to eliminate effects of temperature-difference and combustion. But the results were very erratic, and I could determine no electrical migration of matter through any arc. Such simple experiments are always interesting, and the results themselves remain true. Freshly painted pictures of what goes on—that is, our imaginative conceptions—are important because they lead us to look still further and see better. We visualize now that what goes on in arcs is very complex. From the neutral vapors in the arc-path and from electrons of the cathode are derived various ions, metastable and excited atoms. These latter, in returning to electrical stability, send out radio energy in definite wave-lengths, and their wireless messages constitute the colored lights, spectra of the chemical elements.

Passage of electricity through arcs

differs considerably from the passage of electricity through solutions. Like ferry-boats, suspended particles of most substances carry electricity across a water-gap. This resembles what occurs with many but not all dissolved substances. Such migration is seen, for example, in the motion of the blue color of dissolved copper in electrolysis. Here the atomic ferry-boats are parts of salts or so-called polar bodies. Dissolved sugar, for example, does not do this, but salt does. This seems simple compared with arc-phenomena.

In case of solutions, the generation of electrical energy by batteries, which historically preceded the electro-magnetic method, fits present views of the structure, nature, tangibility, etc., of the thing called electricity, and lets us distinguish between it and its effects. Most present chemical elements, being differing collections of electricity, are stable enough to persist alone, but are often capable of reaching greater stability by mutual reaction. What one element has in excess, another may relatively lack. Under this condition they may send the difference in electricity through a solution. In a Daniell cell, we say that copper comes out and zinc goes into, solution, because of their different atomic appetites for electricity. This difference can be measured as energy between the outside connections. We picture the current flowing in the wire as negative electrons regardless of the distribution between the positive and negative flow through the solution.

I am not trying to impress you with facts but with the pleasure of speculation about them.

For utility we ought to encourage our instinctive interpretations, even though we know that the pictures can not endure unaltered. Fortunately we ourselves are sums of different experiences, so picturing natural phenomena is always a new, personal, subconscious integration. The logic may be very extensive, complex, but, fortunately, it is always individually different. Value is measured by works, and individual contributions may either be firm stepping-stones to better things or perhaps only very useful negations.

Guessing, if you will, is not as much encouraged in youth as I wish it were. I myself cramp and cripple my imagination from habit. When we review a subject like electricity, we find that some one has had carefully to make and test all conceivable guesses, good and bad. Some one digressed with his pure imagination far enough to establish new and useful things, like Franklin's lightning-rod, Faraday's electromagnetic generator or Marconi's wireless.

In 1889 Professor Trowbridge published his book, "What Is Electricity?" He wrote, "This wonderful something we call electricity circulating around coils of covered wire, makes an iron core a magnet," and, elsewhere in the same book, "Is it not possible, therefore, by enormously increasing the frequency of electrical oscillations, to drive them completely off metallic conductors and compel them to be propagated through the ether of space?" That's wireless.

It is this kind of hesitant divination that I enjoy finding in the minds of men. I think some useful people unconsciously, some intentionally, cultivate it, while satisfied and fearful folk deprecate it.

A sealed letter deposited by Faraday with the British Royal Society over a century ago was recently opened. It was sealed and preserved because Faraday wanted the world finally to know that a new view had come to him first, before there was any way to demonstrate it. Faraday had been led to the view that electromagnetic action progresses through space, and, he says, "requires time for its transmission." He even added, "I am inclined to think that the vibratory theory will apply to these phenomena as it does to sound, and, most probably, to light." (We still discuss corpuscular and wave theories of light.) It was not until

thirty-three years after Faraday secretly recorded his thought that Maxwell showed mathematically that electromagnet waves should propagate with the velocity of light. Twenty-two years later Hertz confirmed this conclusion by his striking experiments and it was still nine years later (1896) when Marconi made the whole useful. It is interesting to know that Faraday had that particular vision. But it is important to see that Franklin, Faraday, Maxwell and Marconi were all visionary and practical.

While electricity was once purely spiritual and later less mobile though more liquid, it has in our day taken on still more unanticipated forms. Nowadays all chemical elements differ only in the quantity and arrangement of positive and negative electricity. All compounds are slightly rearranged combinations of what the component atoms possess. Only to a slight extent can we add more electricity to a substance than it normally contains and even then the excess slowly leaks away.

In text-books everything is simple. They usually say, "Atoms are collections of a number of electrons and another part called the Nucleus." Or "electrons are little bits of electricity, always negative," and "they each weigh one eighteen hundredth of the H atom." "They are the fundamental and indivisible units of electricity," etc. I subscribe to such views because they keep us going and guessing. They illustrate pragmatism and are as good as true when they become useful.

Imagine the experiments which can be performed when we feel that "the relative ease with which electrons are lost or gained is one of the most characteristic of all chemical properties."

This, we say, explained chemical electricity. Moreover, all material reactions depend upon it. But so does the permanency and composition of everything, even the countless possible new elements which we make now for the first time, new radioactive matter and isotopes. We imagine that an infinite number of different elements were created at the beginning and all but our 92 mixtures disappeared. They may be replaced. If a few, like radium, attest to the soundness of this view, may we not in some way reproduce or even produce many other elements which will live at least sufficiently long to satisfy some unsuspected future needs? Such speculations, since they lead to experiments, continue a valuable mental process, whatever other product results.

The process of leaking electricity, evidenced in vacuum tubes, opened a very great field in which radio is now the significant part. The expelling force of heat on electricity introduced the new term "thermionic emission." This, we say, explained that old Edison current between the legs of the filament of his lamp. There are plenty more exact expressions of the thing electricity than I am trying to give. I need only say that such new terms as "emission," "grid control," etc., become materialized as in radio tubes long before we can explain electricity. Thus our useful vocabulary grows more complex while we seek to simplify the subject.

We think now that every one knows the electron. It is the indivisible atom of electricity. I hoped it would stay simple. But experts say that it must be regarded as complex, and one adds, "We can not hope to know what electricity is until much more is learned about the electron's structure." Getting at the internal structure of electrons will doubtless proceed, for we appreciate the growing architecture of atoms and nuclei. It will be interesting, disturbing and useful. Thus experience teaches: The more we learn about our ignorance, the larger and more useful it becomes. Electricty is less likely to be confined by our limited concepts the more we know about it, but we may always continue to find new uses for

it. It was simpler as a spirit, but it is more diffuse as it is.

For the present we adhere to the electron as the simplest and smallest bit of electricity. It was wonderful how orderly orbits of these electrons around an imaginary positive center accounted for all the different kinds of atoms. It was marvelous how shiftings of those rotating electrons accounted for the mysterious lines of visible spectra. Then too into this positive center or nucleus were imagined those significant numbers of electrons which determine atomic numbers and the periodic order of the elements. These electron ideas were all valuable steps in chemical understanding. Such disclosures open the way to entirely unexpected experiments which in turn help actually to analyze and synthesize new matter. Thus through even wild speculation, good experimental work is forcefully extended.

Even as an all-pervading spirit, one might expect electricity to come out of a spot made too hot for it, but only those familiar with bees in spring or farmers could have expected electricity to come out when cold light falls on the hive. Photoelectric cells, whose action is due to electron emission from illuminated chemical elements, are already a commercial utility and speak for the sense and versatility of negative electricity.

Even in this general and superficial talk on electricity, it would seem remiss not to do more with the interesting views now being advanced on the composition of the nucleus of atoms—the heart of matter. At this point all matter was naturally looked at as simply electricity, whatever that is. Fortunately, the process of speculative analysis never has to stop, and such unexpected things as a negative charge firmly neutralized by an equal quantity of positive in a hydrogen nucleus is given the name of neutron.

This naturally followed the studies on the electrons. I can not possibly reproduce the pictures of the whole interior of the nucleus, but I can indicate the growing complexity of what was recently entirely an imaginary and indescribable center of electron orbits. Its evident electrical nature now forces experimenters into new territory which every one may later appreciate. The inconceivably tiny nucleus which was first only a positive charge later became very definite mixtures of positive and negative charges, and then mixtures of protons and neutrons. This once simple nucleus is now becoming more and more complex, but always better understood. It is being shot to pieces through electrical bombardments by alpha particles, deuterons, neutrons, gamma rays, etc. In these processes local electrical voltages up to 20,000,000 or more are being recognized just as we speak of billion volt forces in cosmic rays. Such transcendental potentials might have been visualized before, perhaps in lightning, but if the new views of nuclei did nothing but force us to experiment with electricity of such high intensities, they would be ultimately warranted.

Cosmic rays ought to be explained before electricity, for in one way cosmic rays are simple. They cause charged electricity to discharge. A metal point, reminding us of Franklin's pointed lightning-rods, is kept electrified to such an extent that it discharges, or leaks, in irregular shots. Many things may perform this trigger action, but when all such known influences were eliminated, there was still an irregular, uncontrollable shooting out of electricity from the point, and the cause was called the cosmic ray. Experiments above the atmosphere and under earth and water show that the cosmic ray comes from outer space and that it penetrates matter very much more readily than it should if it were an electrical monitor of any known kind. Such things keep good research men avid for new ideas. Scientists want to do something about it, and part of the results are always useful as though our engendered wonderment were not warrant enough.

We were taught that action at a dis-

tance is impossible. Something in space had to handle the energy. One reads the following about electricity: "The energy in the magnetizing coil disappears from the exciting circuit and reappears in the induction circuit. It must have existed during the time of its disappearance and reappearance, in the intervening space." Such published observations produced the imaginary ether. Still more visionary adepts of science get along without it, and so promising experiments are multiplied.

Having once worked in a chair factory, where belts connected every machine to shafts which were obviously driven by the big belt of a powerful Corliss engine, I naturally still look for belts. I realize that imaginary belts called lines of force are simplifications and have replaced leather in most factories.

But I never cease marvelling at the apparently empty but powerful space between the rotor and stator of electric generators and motors. I realize that all the power is in some way shifted from the remote coils to the busy shaft, and yet I can see nothing in the space. I know that my charged balloons may repel or attract one another, and that this would take place whether the electricity is at rest or moving. We remain satisfied until we meet some experience not permitted by our picture. It is then that mental wiggling becomes interesting and application becomes valuable.

Confined to post-factual words, our imagination remains cramped and we are slow in inventing new language to cover what we can not express by previous vocabulary. This is all right, too, because when we invent the new word, we try to express within it the need actually felt for it. By this token, atom, electron, ether and lines of force have a place in our rapidly changing vocabulary and represent a great deal of concentrated and promising ignorance. Justification for all this complication is to be found in the resulting works. Attempts to relegate ether to the place where spirits go lead to fresh imaginings, these to experiments and those to service.

I do not attempt to envelop completely all electricity and its utilities, but I wonder if one can know what it really is without covering everything connected with it.

A new steel mill, making automobile sheets, now rolls hot ingots continuously into thin strips 8 feet wide and hundreds of feet long. The maximum delivery speed of the hot mill is about that of a good trotting horse. The mill operates by electricity. Several thousand motors consume the 20,000 kw. of the plant. Both direct and alternating currents are used, and voltages of 2,300, 600, 440 and 250 seem necessary. Perhaps a complete definition of electricity would include all this kind of data.

Part of this thing we call electricity might be simple. If there is any simple electrical thing, it must be the permanent magnet. Think how long we have known it! But the picture, view, hypothesis or essence of magnetism seems as indeterminate as all electricity. The most powerful magnets are now made of a mixture of iron, nickel, aluminum and cobalt and are much better than steel magnets. I don't see why. We might picture some essence in the property called metallic; but the lodestone, which is no longer metallic but consumed, is also a permanent magnet. So after trying all the hunches on mixtures of metals, any one might imagine a different and still better magnet made from oxides. One man who felt that way, and was unusually visionary, has produced some first-class new oxide magnets. The important thing is, he speculated when he learned some facts. Then he tried his experiments. In general, one can safely say about electricity that there never was so much room for new views and utility, because it never before presented so much of both known and unknown.

You see I am not even trying to explain what electricity is. I'd rather show how rapidly, extensively and intimately it changes, always defying limitations. When it comes to knowing all about it, we have hardly made the start.

One of the earliest electrical investigations was Galvani's research on the nerve of the frog leg, and electrical conduction by nerves has long been an intriguing study. The phenomena are not always simple, but are capable of increased comprehension. The conducting nerve of the frog leg was found to carry electricity by test similar to those applied to conducting wires, and now the radio receiving test is being applied to brain and nerve energy. The fields for further experiment and useful application are unlimited.

I can not leave electricity without referring to at least one of its biological implications. Here, too, my idea is to show how little we yet know and how the interesting unknown grows with new views or imagination. In our radio sets a suitable antenna picks up from space electrical influences called waves, which are reinforced, come from the electrical loud speakers as waves of air in imitation of the noises or music actually made at some distant place. This phenomenon is so common that we forget its physical beauty. But in recent biological experiments it has been possible to pick up close to and yet from the human head electrical waves which are amplified into sounds and recorded as waves on paper. That is the Berger rhythm. This discovery resulted from new views on nervous systems, including the brain, all of which apparently operate electrically. Therefore the motion of electrons of cerebral metabolism may not differ essentially from those of other radio sending stations.

No one can safely predict the outcome of studies in electricity when they involve our bodies, nervous systems and brains. Electricity is, perhaps, like us, various, and yet the sum of all the parts, and certain to be forever growing. The growth will always be due to the inquisitive mixture of imagination and experiment and is in the hands of the young.

ENGINEERING AND HEALTH[1]

By Dr. HARVEY N. DAVIS

PRESIDENT OF THE STEVENS INSTITUTE OF TECHNOLOGY

HEALTH is one of the most precious of human possessions, and serious illness one of life's most heartrending trials. It is not so much one's own ailments that are heartrending—many people bear pain and incapacitation with astounding fortitude and even cheerfulness—but to see a loved one fighting pneumonia or infantile paralysis, crippled by arthritis, wracked by the agony of a heart attack, or bravely enduring the slow gnawing of cancer, and be powerless to do more than stand by and wait, is almost the most distressing of human experiences. Even when there is every hope of ultimate recovery it is hard to be patient; the restless urge to be doing something is almost overwhelming.

Perhaps it is for this reason that generous-minded men and women are so easily persuaded to make liberal gifts to hospitals, to medical schools and to institutes for medical research. Doubtless it was this sort of keen sympathy for human suffering that led Benjamin Franklin to promote, in 1751, the founding of the Pennsylvania Hospital, to write on lead poisoning, to conjecture as to "the cause of the heat of the blood in health, and of the cold and hot fits of some fevers,"

[1] Address at the dedication of the Franklin Memorial, May 21, 1938.

to be concerned about "what is called catching cold," about a cure for cancer and about inoculation for smallpox, to have, in short, such varied interests in the field of medicine as to be elected to membership in the Royal Medical Society of Paris and in the Medical Society of London.

But Franklin was a many-sided man, and we also find him inventing lightning rods, promoting the paving and better cleaning of city streets, discussing the draft in chimneys and the construction of smokeless fireplaces, inventing the Franklin stove or "Pennsylvania fireplace," and, forty years later, describing "a new stove for burning pit coal, and consuming all its smoke," a series of activities that would now be called engineering. May they not, perhaps, have had as potent an influence in promoting the health and physical well-being of his contemporaries as did his hospital?

To modernize the question, to what extent can the engineer be thought of as rivaling the physician in the promotion of health? In appraising this friendly competition, let us not forget that while the engineer's achievements are never so dramatic, spectacular or individualized as is the saving of a life or the restoration of a sufferer to vigorous effectiveness, the engineer deals, not with individuals, as do most physicians, but with the great masses of men, women and children that constitute modern communities. If, then, the intensity factor of his health work is, perhaps, less than that of the physician, its quantity factor is, in general, immeasurably greater. Many more people have used one of Franklin's Pennsylvania fireplaces than ever went to his hospital. And since any appraisal of the effectiveness of any sort of work, in physics or in life, depends on the magnitude of a product containing both an intensity and a quantity factor, and since the intensity factors of the various engineering activities that promote health will, I believe, be found to be far greater than that zero which alone could nullify the significant product, it is, perhaps, not unreasonable to suggest that the engineers of to-day are contributing quite as much to the promotion of health as are the physicians. I say this without any thought of minimizing the magnificent achievements of the medical profession, but merely in the hope that the mention of some commonly overlooked aspects of the work of engineers may bring to them an even greater measure of public understanding and appreciation than they now enjoy.

The virtue of Franklin's lightning rod is that it prevents disaster. A similar service is rendered by modern flood control methods, which often involve engineering works of tremendous magnitude, by the lighthouse service, by the ice patrol in the North Atlantic, by the use of radio on ships at sea, by the intricate interlocking switches, signals and automatic train-control systems on railroads, by the air-beacons, lighted fields, radio beams, blind flying instruments and radio telephones of modern transport flying, and by all the devices and slogans that are making the work of the modern safety engineer so surprisingly effective. If a penny saved is a penny earned, so too is a disabling accident avoided the equivalent of a medical triumph.

Engineers have also done much to help the physician do his work by developing and fabricating for him many useful and even indispensable instruments, such as the x-ray machine, the electro-cardiograph, many devices for electrical and thermal therapy, many intricate optical instruments from the microscope to the cystoscope and all the devices that make a modern operating room, and even a modern doctor's office, such a striking example of twentieth century mechanization. Furthermore, the radio of the engineer has brought to many a disabled seaman medical diagnosis and directions for treatment that formerly would have been wholly unavailable. The contribu-

tion to the effectiveness of health services, the world over, made by the daily broadcasts directed by the Singapore Bureau of the League of Nations is very great. The radium of the physician is extracted from its ore by engineers. In all these ways engineers are helping doctors to do their work more effectively, and thus contributing to the maintenance and promotion of health.

The most obvious, because the most direct, contributions of engineers to the promotion of health lie, of course, in the field of sanitation. By bringing abundant supplies of pure water into towns and cities, a boon that only those who have lived or traveled in arid regions can fully appreciate, by building sewers and sewage disposal plants, by modern methods of refuse-collection and disposal, by the invention and fabrication of modern plumbing fixtures, which make cleanliness easy, and by carrying forward the work that Franklin initiated on the elimination of smoke, engineers have undoubtedly saved many lives and relieved the world of much suffering. And while the medical men have had to lead the way in attacking such diseases as hook-worm, malaria and yellow fever, it has been the sanitary work of engineers that has put this hard-won knowledge into practical effect on a large scale over considerable areas. Indeed in the whole field of public health work and of preventive medicine in which so many forward-looking physicians are actively engaged, engineers are their indispensable allies. The tremendous influence which these various sanitary and other advances have had on the general health level of the population as compared with what prevailed in Franklin's time is too striking for further comment.

In the important matter of diet also, the work of the engineer has been of importance. By the development of tinplate and of intricate machines for fashioning it, he has made possible the canning of food on a tremendous scale, thus broadening and enriching the diet of the nation, and making available at all seasons, and in the most out-of-the-way places, foods rich in vitamins and hormones. The development by engineers of refrigeration on ships, on trains, in cold storage warehouses and in the home, including the newest methods of quick freezing, has contributed to the same end. Irrigation, often involving engineering projects of enormous magnitude, has helped the farmer to produce food in greater abundance and often of finer quality. Still more fundamentally, the ships and trains themselves and the motor-trucks, all invented, developed and fabricated by engineers, are the means by which most of the food of the nation is brought to those who consume it. Without them no modern urban population could exist. By these means engineers have profoundly affected the dietary habits of whole nations and have made possible the elimination of deficiency diseases and of the lowered resistance to infection that malnutrition causes.

In the matter of housing, also, engineers have played their part. They have improved the materials and methods of construction and therefore both the availability and the usefulness of buildings of every sort. They have flooded houses, offices and workshops with eye-saving light. They have transformed Franklin's Pennsylvania fireplace into a central heating plant that provides a uniform controllable temperature throughout a house. Air conditioning is just around the corner. And by developing transportation they have enabled an urban population to find over a far-flung area more healthful living conditions than were available even to the well-to-do of, let us say, the London that Franklin went to in 1757.

In all these ways engineers have contributed directly to the maintenance and improvement of the health of vast numbers of people. This is, however, by no

means the whole story. There are certain other activities of engineers that are, perhaps, not so commonly recognized as having a bearing on the health-level of a nation.

Consider, first, all that is involved in what is called a national standard of living. Technical achievements in sanitation, in the production, transportation and preservation of food and in housing may determine what is available to those who can afford to have what they want; but it is the national standard of living that determines what the average man actually gets. If the national standard of living is low, there will be bad housing, bad sanitation, mal-nutrition, a prevalence of deficiency diseases and a general lowering of resistance to infection and of recuperative power that will be responsible for much sickness and many deaths. By far the most effective way of raising the general health level of any population is to raise its standard of living. This problem is, fundamentally, not medical but economic.

But the standard of living of a community is nothing else than its production of goods and services per capita per year. Unfortunately this is not always the same as a community's capacity to produce per capita per year. At the moment, for instance, we apparently do not know how to make our economic system function in such a way as to permit men to make and consume all they could easily make and would like to consume.

But in the long run the actual production of a community per capita per year will be determined by its capacity to produce, and its capacity to produce will be conditioned largely by the possible production per man-hour of expended labor. In other words, in the long run, the only way to raise the standard of living of any community, and with it the general level of the health of that community, is to increase what a man can do in an hour by giving him more inanimate slaves in the form of horse-power and kilowatts, by giving him more and better tools and machines to work with, by mechanizing and automatizing more of the routine operations in his productive processes, by working out technological advances and inventions that displace some useful thing that is hard to make by something else equally useful and easier to make, by showing him how to handle things more deftly and how to postpone or avoid fatigue, and by more effectively organizing the team-work of the industrial unit in which he works. Only by such means as these can the standard of living of any community be permanently raised. And only engineers can provide these elements in the increased hourly productivity of the workman of to-day and to-morrow. By raising our scale of living in the future, as they have marvelously raised it in the past, engineers can markedly affect the future health-level of the whole population.

Over shorter periods, a high standard of living is characteristic of what we call prosperity. Any one who ventures to talk about the business cycle is treading on dangerous ground. But it is, I think, generally admitted that a characteristic of most waves of prosperity is the rise of an important new industry. The automobile and the radio are striking examples. What the next new industry will be, no one knows. But it is surely safe to assert that, when it comes engineers will have been responsible for its genesis and growth. Only industrial activity, energized by the genius of the engineer, can generate good times. If, then, it is to engineers that we must look both for the long-term trend and for the cyclic bulges in the upward progress of our standard of living, their part in the maintenance and improvement of the health of the nation is great indeed.

All that I have said thus far pertains to the *physical* health and well-being of mankind. But our friends the physicians know even better than the rest of us the importance of that other aspect of men's

lives that may be called *mental* health. Always important in itself, it often influences, if it does not completely dominate, physical condition.

Here particularly we can look to him whom we honor to-day for an almost perfect example of this important human quality. Franklin was indeed, to quote Mr. Julian P. Boyd, "a man unacquainted with inhibitions and repressions and spiritual malaise"; "he accepted the world as given with imperturbable serenity"; he "took it all easily, relishing it, savoring it, without rest and without haste adding to his knowledge, fortifying and tempering his intelligence, broadening his point of view, humanizing and mellowing his tolerant acceptance of men and things." I know of no better description of mental health. Nor do I know of any better prescription for living happily, as Franklin did, to the age of eighty-four years.

But how, you may well ask, can engineers contribute to the wide-spread diffusion of such mental health as this? It is, of course, too much to hope that large numbers can ever be brought to anything like the perfection of sanity, poise and serenity of Benjamin Franklin; but to bring any considerable number of men and women even a little nearer to perfect mental health would be an important achievement. This, I think, engineers can help to accomplish in at least two ways.

The first depends on the fact that a considerable proportion of men and women spend more than a third of their waking hours on an industrial job of some sort. Some one has said that the chief difference between a professional man and a job holder is that the former lives through his work, the latter by means of it. I see no reason why this cynical characterization of industrial work should be accepted as inescapably true or why such work can not be made to afford to the worker an acceptable and satisfying way of living. The old-fashioned craftsman thoroughly enjoyed his work—at least many modern writers seem to think he did. And I believe that many of to-day's workers enjoy the part they play in industry. We are all too likely to ignore all the non-financial incentives and rewards of business and industry.

But enjoying one's work is greatly enhanced by, if it is not actually dependent on, having a job that one can do well. This is where the engineers come in. They are beginning to feel their way into new fields of management which involve both adjusting jobs to their holders and assigning men to the right jobs.

Adjusting a job to its holder may be done by a machine designer or by a motion-study specialist. Many modern machines are designed with special reference to the convenience and comfort of those who are to operate them; though how much remains to be done is indicated by the saying of one of my friends that there is only one machine in the world that is perfectly adapted to the operator, and it took three thousand years to do that—the machine in question being the axe-handle. And to the extent that motion-study is used to make jobs easier and less fatiguing, rather than merely to speed up production, it can confer great benefits on the worker.

Assigning men and women to the right jobs holds even greater promise of materially raising the general level of mental health of the working population. Industrial managers are beginning to make notable progress in studying human beings objectively, in measuring individual differences, in appraising both the strengths and the weaknesses of prospective employees, in cataloguing the pattern of strengths and weaknesses most appropriate to each particular job and in assigning men and women to the right jobs. I could tell you, if time permitted, of men who came into an industrial testing laboratory restless and inefficient, sometimes even morose and uncooperative, because

they had strong aptitudes of certain kinds on which their jobs made no demands whatever, and how, in many cases, reassignment of these men to jobs that called into play all their aptitudes resulted within a year in almost miraculous alterations in personality and outlook on life. I could tell you of women, trained at their own request as comptometer operators, who became nervous wrecks within a year because of the lack of a certain necessary aptitude which could easily have been detected in advance. Nor should we forget the intangible but often important stimulation to personality that comes from the mere fact that one has been studied and measured, that one's abilities have been sought out and recognized, that one's life has been paid attention to and discussed as an individual adventure. Not that the millennium is immediately at hand by any means—the engineer-managers of to-day have only just begun to scratch the surface of this highly promising field—and he who tries to go too fast in it will come a cropper, and perhaps temporarily discredit the whole field. Nevertheless I am convinced that this kind of activity will produce, in the next twenty-five years, a greater harvest of human satisfaction and mental health than any of us can yet conceive of.

Turning now to the second way in which engineers can hope to help bring more abundant mental health to the world, we find ourselves facing a much more difficult problem. Perhaps I am over-optimistic in even mentioning it as one that engineers or any one else can hope to solve. And yet, in its various ramifications, it is probably the most important problem that civilization faces today. I refer to the problem of industrial instability, the problem of the recurrent recessions and depressions that periodically throw millions out of work and disrupt, sometimes permanently, the lives of many of them, the problem of social insecurity.

That social insecurity can profoundly affect the mental and even the physical health of great numbers of people is indubitable. Worry has wrecked more lives than tuberculosis has. And there is no worry so insistent as that which besets a self-respecting industrial worker and his whole family, if he thinks there is danger of losing his job, except that of the worker who has lost his job. I suspect that this sort of worry is by far the most important single factor in the American health situation to-day.

What hope is there of lightening this incubus of fear caused by industrial insecurity? What hope is there of steady, perhaps even of guaranteed employment?

Two types of thinking are current with respect to problems of this sort, one political, in the best sense of that word, the other industrial. It is characteristic of the political type of thinking, whenever a social problem can be defined at all, to attempt to solve it by enacting a law. This type of thinking holds, consciously or instinctively, that social progress can best be forced forward by legislation. This dogma, to those who are persuaded of its validity, is comforting. It affords them an opportunity to do something about it, here and now, without waiting for the slow processes of social evolution. In some cases reform by means of legislation is indeed the only practicable procedure, particularly when a recalcitrant fringe of unsocial competitors has to be whipped into line with the standards which a great majority would be glad to maintain if they could. But to coerce a majority to proceed faster along the path of social progress than they are ready to go is a process both difficult and dangerous, even though alluring. In such a case, education is more to the point than legislation.

The political type of approach to the problems of to-day may, of course, succeed in remaking our world, particularly if it be reinforced by plenty of emotion-stirring propaganda. It may even lead

to the most effective forms of government that the world has yet seen. These new forms of government are, however, almost certain to be highly centralized, closely integrated forms of government, exerting over industry and over the lives of citizens generally the detailed regulation and control which seem to be essential to making any planned economy work. Personally, even if I were sure that the political approach would lead to highly efficient governmental forms and to really well-ordered lives, I would rather sacrifice some of this efficiency and orderliness to secure more individual initiative and responsibility, more of a chance for each of us to make his own mistakes and enjoy his own triumphs.

The industrial type of thinking about economic and social problems proceeds in quite a different way. Too often in the past, unfortunately, it has tended to ignore such problems altogether as long as possible and, when at last they loomed up inescapably, to try to fight them instead of to solve them. But the industrial leaders of to-day are beginning to have an economic and sociological background with which to think through the remoter human implications of the decisions they make and the policies they pursue. They are beginning to work out, step by step, each in his own business unit, some sort of social justice with respect to the conditions and rewards of industrial work and the effect of it on the whole lives of workers. The industrial type of thinking pins its faith to the hope that all these tiny steps forward, scattered all over the country and through many industries, influencing each the other both by the contagion of example and by the educational process of thoughtful discussion, will integrate into a march of progress that, however halting and irregular it may at times appear to be, will have firm ground under its feet.

The key to the whole economic and social situation, according to this way of thinking, is the breeding of a sufficient supply of industrial administrators who have not only sound business judgment but also enough social understanding and vision to better adjust the functioning of our present economic and industrial system to the welfare of society at large. Many of us are hoping that such progress will be made rapidly enough to forestall the motivation for and the possibility of too much legislative experimentation.

But, you say, where do engineers come into this picture? The answer is that more and more are engineering-trained men finding themselves in positions of executive responsibility in business and industry. There seems to be something about the training and experience of engineers that fits them for such work. Instinctively they deal with facts rather than with traditions and emotional reactions. Their work forces them to see things in the large, to fit details into long-range plans, to see visions and dream dreams and then translate them into reality by the careful organization of a multitude of various contributing activities. I believe that engineering-trained men are destined to contribute far more than their proportionate share of the industrial leaders of the next quarter century. If so, they are facing a great opportunity and a great responsibility. If they can learn to think around their jobs as well as thinking their jobs through, if from their natural vantage point as liaison officers between capital and labor they can get a comprehensive vision of the aims and aspirations and points of view and prejudices of both groups, if from their familiarity with the flow of materials through a factory or the flow of energy through a power plant they can derive a vivid picture of the flow of goods and of money through the channels of production and consumption, if their experience in handling men on the job can bring to them some understanding of how men want to live, they can, perhaps, contribute more than any other single group

to the solution of those fundamental economic and social problems of which we have been speaking. And if by these means they can, even to a small extent, diminish the worries inherent in industrial insecurity, they will have made the greatest contribution of the century to the promotion of the mental health of vast numbers of people.

May I then suggest that he who is profoundly interested in maintaining and improving the health of mankind and who has enough vision and imagination to sense the long-time trends of life, would do well to devote a considerable part of his energy or of his beneficence to fostering engineering education and research. In particular he should be interested, not only in the technical aspects of the profession, but especially in those branches of it which are concerned with industrial management and with the foundations on which sagacious industrial administration must rest. The results will not be so easy to observe, so directly and immediately obvious, as if he had been instrumental in training a succession of wise physicians or skilful surgeons, or in conquering some obscure disease, but in the long run he will accomplish much improvement in both the physical and the mental health of his fellow men.

COMMENTS ON CURRENT SCIENCE

By SCIENCE SERVICE[1]

WASHINGTON, D. C.

A DISCOVERY MADE BY A TINY TELESCOPE

You rightly hear much about the giant telescopes having 100-inch and 200-inch diameter mirrors and the wonders of the heavens they show and will reveal. But it should not be overlooked, as is sometimes done, that excellent and important work is being performed with small equipment.

The discovery of the brightest stellar object ever observed—having a luminosity equal to 400,000,000 suns—which was recently announced by Professor Fritz Zwicky, of the California Institute of Technology, is a splendid example of a major discovery made with a tiny telescope.

Using a small 18-inch Schmidt type telescope, Professor Zwicky has been photographing the sky for over a year at Mt. Palomar on the site of the great future observatory which will house the still-to-be-completed 200-inch diameter telescope.

With this Schmidt astronomical camera, having an extremely wide field of view, Professor Zwicky has obtained some 600 good photographs of distant nebulae.

Three super-nova stars were found, giving complete confirmation for the previous suspicion of the existence of two types of temporary stars; novae and super-novae.

It was one of the super-novae, known as I. C. 4182, which has turned out to be the brightest stellar object ever discovered, according to calculation by Professor W. Baade, who is Professor Zwicky's colleague.

Novae are stars which may have been known for years as well-behaved members of the galaxy that suddenly flare up into flaming brilliance for a short while and then drop back into obscurity. What causes these outbursts of brilliance is one of the mysteries which astronomers ever seek to track down. Professor Zwicky's work is added additional information that brings nearer the day of clear explanation.

THE RECOVERY OF LOST RADIUM

You probably have not met a "radium hound," but he is a valuable creature, with a very scientific ability at playing "needle in the haystack" to the tune of thousands of dollars. He is in a class with divining rods. Who named him is not known, and fortunately his pointing abilities are not frequently required.

Born in the physics laboratory, the "radium hound" is not a dog but an instrument, either the electroscope or the Geiger-Muller counter, both of which are affected by the gamma radiation given off by radium.

Radium is precious stuff and when it is used in the treatment of cancer and other diseases it is sometimes lost. The amount used is so small and seemingly insignificant that patients often can not be made to realize its value. A hundred milligrams in the form of a salt occupies the space of about a quarter inch of pencil lead. In former days this small amount cost $12,000, and while the price of radium has been reduced materially a heavy investment is still necessary.

Dr. Robert B. Taft, of Charleston, S. C., has compiled amusing anecdotes and statistics on radium losses and the methods of recovery. There are 107 records

[1] Watson Davis, director, Frank Thone, Robert D. Potter, Jane Stafford, Emily C. Davis and Marjorie Van de Water, staff writers.

of losses with 59 complete and 11 partial recoveries.

In one case Dr. Taft found some radium that had been on a dump for several weeks. In another case he saved an innocent man from going to jail on circumstantial evidence of radium theft. When the radium was located with the "radium hound" instrument, he was absolved, which Dr. Taft considered worth more than the money involved.

So sensitive are the radiation counters used that whole houses can be searched for radium from the outside in cases of suspected theft. Since radium can cause dangerous burns if it remains near a person unshielded, the "radium hound" gives reassurance that lost radium is not located where it will cause harm.

The prize radium hunt, in Dr. Taft's opinion, ended in the stomach of a pig. The radium was lost in a hospital, the rubbish from which had been taken to a pig farm. This was a case of "complete recovery of radium, complete loss of pig."

DISCOVERY OF THE SWEETNESS OF SACCHARIN

Many of the older generation can remember the newspapers in 1884 and their stories of a new kind of "sugar" which was 500 times sweeter than the ordinary variety. And they may have read speculative tales, too, about the potency of the grain alcohol which could be made out of this new sugar. Actually what was reported was the discovery of the chemical saccharin, completely unrelated to sugar in a chemical sense, and without any fermentation properties.

Saccharin was discovered in the work of the graduate student, C. Fahlberg in the laboratories of the then-famous Professor Ira Remsen at Johns Hopkins University.

Two stories exist about the discovery of saccharin's sweetness which bear retelling. One runs that Professor Remsen was lecturing to his class one day with samples of many newly prepared chemicals before him on the table. During class he unconsciously poked his pencil into several samples.

Later, in his office, he puzzled over a tough problem and touched the tip of the pencil point to his lips. Its amazing sweetness sent him scurrying back to the lecture hall, where he systematically tasted all the chemicals until he found the one prepared by Fahlberg at his direction.

The other story, related by Fahlberg in Berlin in 1904 at a chemical congress, tells how he (Fahlberg) had been working all day in the laboratory. After washing his hands he went home to supper, but the bread and everything he handled tasted very sweet. He soon found that the sweetness came not from the food but from his hands and even forearms.

The rest is quite similar, with Fahlberg tasting all the chemicals he had encountered that day. Remsen and Fahlberg's original paper on the discovery of saccharin was published in 1879. Their experiments were performed just 60 years ago, in 1878. The press of 1884 was only five years late with the news.

JAPANESE PYRETHRUM MONOPOLY

The highlands of Kenya in East Africa, just south of Ethiopia, are the newest spot where attempts are being made to grow pyrethrum flowers, whose extract goes into insecticides that must be harmless to man and animal. Fly sprays are a major product using pyrethrum, although it enters into the composition of certain sprays for garden crops.

This bit of information may not set America tingling with its significance, but one can be sure that Japan is keenly aware of the African pyrethrum plantings because the little pyrethrum flowers form one of Nippon's much-prized cash crops.

Japan in fact produces about 95 per cent. of the world's pyrethrum, and the United States, using some 20,000,000 pounds a year, is half of the world market. In Japan, pyrethrum is comparable with cotton in the southern states as a cash crop.

A report in *Industrial and Engineering Chemistry* on the Kenya pyrethrum plantings and harvest shows that the little flowers of African cultivation are superior, in their potency, to the Japanese variety. While pyrethrum plants have been grown in many parts of the world—California, Lancaster, Pa., and Colorado are three American examples—it is only in Kenya that a product superior to that of Japan is obtained.

Although the United States uses large amounts of pyrethrum it is unlikely, in the near future, that it can be grown economically here in competition with foreign lands. The pyrethrum flowers are picked by hand and the cheap labor of Japan and Africa has the situation well under command.

THE DOMESTICATION OF THE AFRICAN ANTELOPE

Farmers in Africa may some day be able to harness big antelopes to their plows, and have their meat to eat and their hides to make into harness and boots. Domestication of the eland, an antelope bigger than most oxen, is suggested by Professor Caesar R. Boettger, of the University of Berlin, as a possible solution to Africa's cattle-pest problem.

The tsetse fly, Africa's most dreaded insect, is making parts of the continent uninhabitable because it carries the germs of a disease deadly to domestic cattle and other live stock of non-African origin. It deprives the natives of their chief form of wealth and makes farming impossible to white settlers.

The native fauna of Africa are not totally immune to the tsetse-borne disease, ngana, but they are highly resistant to it. They survive when ngana wipes out whole herds of domestic cattle.

The chief obstacle to be overcome in using the eland or some other member of Africa's rich population of large hoofed animals is their alleged untamability. None of them has ever been domesticated in modern times.

However, Professor Boettger believes that the difficulty lies not so much in the psychology of the animals as in that of the natives. They have just never taken the trouble to try, he thinks, and he points out the success of the Belgian efforts in the Congo, in making good work-animals out of the supposedly untamable African species of elephant.

Once in the remote history of Africa antelopes were kept in man-tended herds, Professor Boettger states. Monuments of the oldest dynasties in Egypt show herds of three antelope species kept within enclosures. Antelope-keeping became a lost art, however, long before the end of antiquity in Egypt; perhaps because imported cattle were easier to manage and more profitable.

Immediate success could not be looked for, perhaps. But, probably, our Neolithic ancestors had to work on cattle, horses and other animals for many generations before they became tractable and really worth their keep.

THE ORIGIN OF CORN

Corn has long been one of the greatest of botanical riddles. Nobody has known where it came from. Wild forms of most other grains are known, but corn has remained a botanical orphan. Not only does it lack any identified ancestors, but it has only two cousins in the Western Hemisphere: teosinte, which is a Mexican fodder plant, and a wild grass named Tripsacum.

Now come two Texas scientists, Dr. P. C. Mangelsdorf and Professor R. G. Reeves, with strong evidence that the ancestor of corn is corn—a primitive type of grain known as pod corn, in

which each grain is covered with a tiny individual husk of its own. Pod corn is unknown in the wild state, but even as a cultivated plant it has certain definitely "wild" characters.

One suggestion that has in the past had the support of some botanists, namely that teosinte is the ancestor of corn, they dispose of very neatly by adducing good genetical evidence that corn is one ancestor of teosinte, the other being the related grass Tripsacum. They hold that teosinte originated as a natural hybrid, probably when the migrating Mayas, about A.D. 600, carried corn into the natural range of Tripsacum in Mexico.

One difficulty about the wild pod corn hypothesis is that the Peruvian Indians, who without much question originated corn culture, are the only ones who do not grow pod corn at all. But, reasoned the two scientists, not unlikely the Peruvians had carried their agriculture to such an advanced stage that they discarded pod corn long ago, while less advanced Indians still used it.

So they leafed through old manuscripts, examined effigy pottery from the very earliest known Peruvian culture levels. Finally, at the Peabody Museum of Yale University, they found a faithful replica of a prehistoric ear of pod corn.

They do not feel that the wild form of corn is necessarily extinct. It may still exist, they think, in the little-explored unforested lowlands of southwestern Brazil, Bolivia or Paraguay.

THE VALUE OF LEGUMES

Legumes—lespedeza—forage crops—and a lot of other big words are meaning much to farmers these days, when soil improvement is almost as important as crops.

Legumes have the happy faculty of enriching the soil on which they grow so far as nitrogen is concerned. They take nitrogen directly from the air and manufacture it into plant food, through a partnership arrangement with bacteria that live on their roots.

Alfalfa and red clover are the commoner legumes, but the vetches, field peas and the annual lespedezas are also important.

There are others that most peoples have never heard of. The agronomists and plant breeders have them tucked away in their experimental plots, testing them, seeing what they are good for. Some of them may be the legumes of the future, plants that will allow the farmer to get crops profitably from unpromising land.

One of the most intriguing is a kind of lespedeza that does not need to be planted each year. This perennial species, *Lespedeza sericea*, comes back year after year from the crown as in alfalfa. It is still somewhat of a novelty in spite of its introduction from China before the turn of the century. Although grown commercially, it is still something to show visiting agriculturists at such places as the Tennessee Experimental Station or Arlington Experimental Farms near Washington.

Older stands grow tall and bushy. Hay can be cut from it two or three times a year. One fault is that it contains too much tannin, the stuff used for tanning leather, to please live stock too well, but made into ensilage the tannin content is reduced so that stock eat it readily.

It produces lots of seed which is beginning to be used in poultry feeds. Better learn how to pronounce lespedeza.

THE DANGER OF LAXATIVES IN APPENDICITIS

Too many persons are dying of appendicitis, in spite of campaigns to reduce this mortality and in spite of a quite recent downward trend in the mortality. This opinion, held by many authorities, is reaffirmed in a statement from the New York State Department of Health.

Appendicitis ought to be, as Dr. Reginald Fitz of Boston points out, "a disease easily diagnosed, of no great danger, and when recognized early and submitted to proper treatment, readily amenable to cure."

Improper use of laxatives and delay in removing the inflamed appendix seem to be the chief factors that keep the appendicitis death rate up. On the laxative subject, Dr. J. O. Bower of Philadelphia is authority for the statement that between 1918 and 1935 "248,000 . . . have been literally slaughtered with laxatives."

Dr. Fitz cited figures from Peter Bent Brigham Hospital in Boston showing that of 65 patients who died of appendicitis, 74 per cent. had taken some sort of cathartic before entering the hospital, whereas of 100 patients who recovered, only 51 per cent. had taken a laxative.

The same cases also showed the effect of delay in having the appendix removed. None of the patients who died was operated on within 12 hours and only 11 per cent. within 24 hours of the onset of acute abdominal pain or bellyache. Of the patients who recovered, 8 per cent. were operated on within 12 hours and 25 per cent. within 48 hours of the onset of pain.

If the abdominal pain or bellyache lasts over four hours it is probably serious. Authoritative advice in such cases is: Call a doctor, do not eat or drink, do not take laxatives or cathartics.

Sometimes appendicitis follows a blow on the abdomen. Doctors are not agreed whether in such cases the blow was the sole cause or whether it precipitated an attack in a previously inflamed appendix. The important point is that such cases of appendicitis are unusually severe and demand immediate surgical attention.

RECREATION INTERESTS AND AGE

Church-going still leads as a leisure-time activity, if a sample of the Missouri population may be considered as typical of Americans in general.

And church-going is one of the few interests that do not fall off with increasing age, according to a survey conducted by Dr. Eugene S. Briggs, of Phillips University, Enid, Okla., and reported to *School and Society*.

Old age and increasing enforced leisure seem inevitable, unless one is to escape through death. Yet it is surprising how many of our recreational interests are those that do not appeal to the aged.

Even the movies fail to hold the elderly, those who never attend increasing steadily from 18 per cent. at 20 years to 50 per cent. at 40 years, 72 per cent. at 60 years and 100 per cent at 90 years, Dr. Briggs found.

Card playing, dancing, radio listening and even the entertaining of friends lose interest as we grow older, it seems.

Age does not affect concert or lecture attendance.

Hobbies are enjoyed by only 39 per cent. of adults, but appeal particularly to men and women between 65 and 75 years of age, 95 per cent. of whom ride a hobby. Hobbies hold the better educated and the city dweller, Dr. Briggs discovered.

Athletic sports are not participated in much by adults, even if horse shoes are included, Dr. Briggs said. Only one in ten country folks play athletic games as often as once or twice a week. Here again the interest wanes with increasing age.

Of all adults who read newspapers, 40 per cent. find recreation in so doing. A similar percentage find recreation in reading magazines.

Books are not very popular, for 60 per cent. have read no books in the past six months. And if you think that books are neglected only by those remote from libraries, you are due for a surprise. The greatest number of non-readers of books were born in the city.

CITIES AND NATIONALISM

By Professor EUGENE VAN CLEEF
THE OHIO STATE UNIVERSITY

CITIES are social organizations expressive of man's gregarious habits. They are functional indices to the cultural and economic structure of the regions of which they are a part. Cities are born, develop with varying characteristics sensitive to internal and external influences and, like the humans of which they are constituted, decline. Evidence is abundant that they are unstable. Yet, few persons are fully conscious of this fact. "The Fall of Rome" makes little impress beyond being an attractive expression connoting a more or less mystical event of the dim past and, incidentally, has a euphonious ring. The decline of Tehran, Merv, Bukhara or the disappearance of Tyre and Sidon causes no disturbance among us who to-day are far removed from the sites of these centers—far removed historically as well as physically. Even the succession of remains of recently extinct lumber towns in the Great Lakes Region or mining communities in the eastern coal fields fails to arouse concern among our confident citizenry. Yet, if it be true that instability even to the extent of threatening the very existence of a city is a reality, that fact is of such profound significance that it should excite the interest of every one. Our failure to recognize this critical aspect of the national well-being will make impossible a satisfactory adjustment of the nation to the social and economic revolution now in progress.

Cities are closely integrated with rural areas both in an economic and a physical sense. As cities expand areally, they do so at the expense of rural lands. Likewise, as their population grows, their economic pressure upon agricultural producers is increased. Thus as cities reduce the area of agricultural lands, they demand more food. Increased production may arise from more intensive cultivation of the lands in the *umland* (immediate vicinity of the city), and on lands in more remote areas or by bringing under the plow, lands not heretofore worked. Whatever the means, the fundamental premise that the reciprocal relationships between city and rural populations give rise to points of friction, clashes of interests and to various types of economic and social interdependence, calls for a careful appraisal of these two population elements which constitute the nation.

We recognize that the horizontal growth of cities is not only inevitable but is essential to the welfare of a properly planned city. As the means of communication become increasingly effective, reducing distances in terms of time from hours to minutes, suburbs and satellite cities are drawn functionally within the confines of the central city itself. Likewise, the reduction in time closes the areal gaps between cities and extends the radius of influence of each of them. Interrelations between urban and rural areas, among urban centers and even between states, become increasingly complicated. The city no longer remains a provincial entity with purely local interests, but acquires regional characteristics, and regionalism implies a certain responsibility associated with nationalism.

During the era of the New Deal, the spirit of nationalism as expressed by an increasing concentration of power in the Federal Government has grown at an alarming rate. We grant the desirability

for cities to recognize the national government as a possible harmonizing and coordinating agency. However, a people who seek to preserve freedom of action which a democracy is supposed to afford, dare not surrender its own privileges in favor of remote control by a bureaucratic régime. The theory of those in the national capital that the clash of urban and rural interests can best be alleviated by a nationalistic organization is based largely upon the supposition that agriculture is nationalistic rather than local in relation to the consumption of its yields. The theory further builds up the idea that the significance of state boundaries has disappeared owing to the nature of present-day convenient and rapid means of communication. Hence, the nation can be more effectively directed by its division into more or less natural regions responsible directly to Washington. Apparently, cities within the regions are to become subservient to a regional directorate. Submission to this plan means surrender of democracy in the cities.

A Finnish writer remarking about the urge toward self-sufficiency and centralized control in the modern state has said: "The idea of the state and the idea of the city are contrary notions." Here is a philosophy worthy to ponder over. A nation is essentially fixed in area and boundaries; a city, as we have already indicated, is flexible. It is a competitive organism which rivals other centers in the struggle toward economic and social achievement. The national state as the dominant directing force in the destinies of a city will resolve the latter into an impotent element and reduce it to the level of its weakest competitor. Nations depend upon cities for their existence; not cities upon nations. Preservation of the city as a virile, dynamic element is essential to the preservation of a strong nation.

When proud Athens and powerful Rome lost prestige, the Greek and Roman empires fell with them. When the cities within these empires ceased paying tribute (taxes) to the central government, that government collapsed, but not so the city. Cities, in fact, in early European history tended to become self-sufficient and often did attain independence. Feudalism was essentially one such form of independence. In the course of the centuries climaxed by the industrial revolution, cities arose in ever-increasing numbers and, by different means unnecessary to detail here, grouped themselves under central governments to become nations. Germany, itself, a loose confederation of states until 1871, to-day is largely a collection of cities and city-states, most of which are losing their independence. The continuing character of cities has been illustrated within the past two decades, when many European boundaries have dissolved, but the cities within them have survived. Royal Riga, formerly in Russia, thrives as the capital of Latvia; venerable Strassburg, in pre-war days a commercial center in Germany, to-day pays taxes to France; cosmopolitan Trieste, which served old Austria-Hungary, still functions as a port but under Italian rule; bold Beograd (Belgrade), once the capital of Serbia, pays homage to the government of Yugoslavia; and Wien, at the cross-roads of important central European trade routes, no doubt will continue to play a conspicuous rôle even though it has shifted from Austrian to German rule.

Agricultural experts often refer to the dependence of cities upon rural areas for population supply as one argument in favor of greater consideration for the farmer. The implication is that without the farmer there would be no city population. Hence the farm population is the be-all and end-all of our preservation as a nation. Naturally, it is futile to argue which of two reciprocal elements is the more important. However, we should

note that cities actually do not consciously import farm population in an effort to maintain themselves. O. E. Baker, a government expert in farm economics and population movements, has cited the following elements which "tend to push the young men and women off the farms": (1) the rate of natural increase of population; . . . (2) technical progress . . . ; (3) depletion of soil fertility . . . and (4) devastation of crops and livestock by pest and diseases." Of course there is always the lure of the city with its excitement, bright lights, supposed opportunities, wages in ready cash and still other seeming advantages to attract the rural folks. But the city does not grow because it wantonly entices persons from rural districts.

Most of the motivating force behind the migration of population from rural to urban habitats has originated in the rural habitat itself. City and urban areas being interlocking parts of an economic structure they can not be divorced without destroying that structure. Improved means of communication, including rail facilities, automobiles and good roads, regularly scheduled airplane services, wired telegraph, radio and motion pictures, have virtually knit rural and urban areas into a single biological unit. No longer are the peoples of these regions and their respective activities strange to each other. On the contrary, their differences grow less and less, while their similarities tend to become identical. We may well view our population composite as distributed in agglomerations made up of people who are engaged in manufacturing and distributive services (city people) on the one hand and producers of foodstuffs (farm people) on the other hand. The conflicts which seem to arise between peoples of urban and rural areas are due to a lack of appreciation of the mutuality of their respective services. Mark Jefferson has said: "What is rather carelessly called rural population is only the least nucleated part of a highly nucleated whole. . . . Rural folk awake and at work are tied up to the city in every act of life."

If, then, the city is the keystone of the nation, any attempt by the national government to serve as a paternalistic authority operating under the guise of seeking to establish equality in purchasing power and wealth for all, is certain to weaken that keystone and to cause the collapse of the entire structure. If we would not follow in the wake of European nationalism which is already challenging the individuality of cities and dulling the senses of the people, we must plan our future so as to maintain the vigor of our cities as well as that of the rural element. Such planning must proceed upon the philosophy that the city plus its continuous hinterland is the climax expression of a nation's level of civilization.

THE FORCES WHICH GOVERN THE ATOMIC NUCLEUS

By Dr. M. A. TUVE

DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, WASHINGTON, D. C.

(A) Introduction

When we speak of the forces acting deep within the atom, just what do we mean? And how valid can our ideas and statements be about anything so far removed from our direct perception and experience? The extremely small dimensions of the central heavy cores or nuclei of atoms of the various chemical elements have been measured by very direct methods—by simply shooting high-speed particles (nuclei of hydrogen or helium atoms, for example) at thin films of materials and observing that hundreds of millions of these particles pass straight on through for every one that is appreciably deflected. All solid bodies are literally full of holes, because all atoms are comprised largely of empty space; they have their mass or weight almost entirely concentrated in these central nuclei, a hundred thousand times smaller than the atoms themselves. The relatively large dimensions of atoms are simply the dimensions of the atmospheres of light-weight electrons which surround the atomic nuclei. How do we know that even the *idea* of a force has any meaning in a region of space ten-million-million times smaller than our own thumbs and fingers?

The answer is of course that we simply define what we mean by force, and the question then transforms itself into asking whether the ideas of force and energy and mass and momentum, which we define in accordance with our experience with larger things, are *useful* ideas in a discussion of these small regions.

These, then, are the primary ideas. We assume that mass or inertia is a basic property of the small particles of which matter clearly appears to be built, and that mass, measured in accordance with our definitions, cannot be created or destroyed; then we inquire the extent to which these ideas, together with the familiar concept or definition of force, are useful in the sense that by using them we are enabled to predict the behavior of the atomic or sub-atomic particles under given new conditions from our observations of their behavior under other different conditions. The answer to our question, as I hope to indicate, is that force and mass are useful ideas in a discussion of atoms, in fact to a remarkable degree. We are able to organize nearly all the information we have about the inside of the atom, and about the interactions between atoms, in terms of force, mass, energy and momentum, just as these concepts serve us in the physics of things of ordinary size. I shall point out also, however, that certain puzzles most certainly still remain.

(B) The Primary Physical Forces

The main ideas to be presented in this lecture can be outlined very briefly. It will be a flattery of my powers of exposition if even three main points can be made to appear worth remembering about a subject as far removed from your own work and interests, presumably, as the forces which act inside the atomic nucleus.

One point is this: Physical science is now so comprehensive in its scope that we can describe all the interactions between material bodies in terms of just three different kinds of forces. All the welter of actions and reactions in the world of physical things, from astronomy down

through mechanics and heat and radio and light, and on down through chemistry and atomic structure and into the atomic nucleus itself, all these phenomena can be described as expressions of just three fundamental forces, namely, gravitational forces, electromagnetic forces and the forces which govern the atomic nucleus. Perhaps these three forces may ultimately be reduced to different aspects of some one great, all pervading and all-inclusive type of force, but for the present we should be satisfied to have them reduced to only three. The description of the whole universe in terms of just three kinds of forces is a truly astounding simplification of the near-chaos in which we appear to live.

A second point is that when we make our analysis fine-grained enough to deal with the atom and its parts we have to introduce two elements into our formulation which are not necessary when we deal with things or systems of ordinary size. Every one is familiar with the fact that in dealing with gravitational forces the ordinary analysis had to be modified by the introduction of the concepts of the relativity theory when the analysis was extended to extremely large dimensions. Similarly, when we go in the direction of extremely small dimensions and deal with atoms and atomic parts we find it necessary to make two modifications—we must introduce an element of discreteness or discontinuity, as indicated by the name "quantum theory," and we must take account of what is called the phenomenon of exchange, which I shall attempt to illustrate later. These two modifications grow out of our recognition of the essential limitations of our concepts of the real nature of matter—the nature of particles and the nature of waves—when we carry these ideas down to the most exaggeratedly microscopic dimensions. This is just another repetition of the old dilemma of particle-theory versus wave-theory, well illustrated by the history of theories regarding the nature of light. Newton explained light in terms of particles; the discovery of phenomena of interference a century ago required light to be wave-motion; to-day we know that there is an essential duality about light—it has both wave-characteristics and particle-characteristics. Similarly with our understanding of atoms we have a duality of particle- and wave-properties, as expressed in the modern form of the quantum-theory called the wave-mechanics.

The third point which might be remembered refers to the distinction we make when we speak of a problem or a difficulty as "fundamental." A fundamental difficulty means a trouble which is inherent in our basic concepts, the failure of the idea itself, as distinguished from a difficulty of complexity, the failure of our mathematical or experimental abilities to meet the needs of a problem. It is impossible, for example, to write down a detailed mathematical solution describing the motions of a hundred particles all interacting simultaneously with each other—even the classical three-body problem can be solved only with restrictions—but the interaction of two bodies represents no such difficulties of complexity, and if our formulas fail to describe a two-body atomic problem correctly, for instance, we know that there is trouble with our ideas or concepts themselves. It is this kind of a formulation of what we mean by a fundamental problem which has kept the emphasis of the work in our laboratory at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington so definitely concentrated on problems which are essentially simple, such as the interaction of a proton with another proton, or of a proton with a neutron. Protons and neutrons are the primary heavy particles out of which the nuclei of all atoms are built. (A proton is the nucleus of an ordinary atom of hydrogen; the neutron is a particle of the same mass but without the

positive charge of one electron which is carried by the proton.)

(C) Nuclear Physics and Magnetism

Before we proceed to a discussion of the various experiments which give us direct information about the behavior of matter inside of the atomic nucleus I might indicate the facts which led to such investigations being carried out at the Department of Terrestrial Magnetism of the Institution. Reminding you of what I have just said about the meaning of fundamental problems, the briefest way to state it is to say that our studies of the atomic nucleus and of the simplest interactions of the primary particles of matter constitute an effort to carry out the most fundamental investigations which it is possible to formulate regarding the basic nature of magnetism itself. This means finding out the laws governing the interactions of magnetic bodies or particles in the most exaggeratedly fine-grained case which we can examine. I need only remark further that at the time when the department's program in nuclear physics was inaugurated in 1926 by Dr. Breit and the author it was just being discovered, and has since been amply demonstrated, that one of the very few—three or four—known attributes of the primary particles of matter is the fact that they all possess magnetic moment or intrinsic magnetization. As far as the magnetization of the Earth is concerned one must say that such studies as these have little or no significance beyond the rather important one of a fundamental understanding of—learning the fundamental laws of—the phenomenon of magnetism with which we are concerned. The problems concerning variations of the Earth's magnetic field can now be accounted for in considerable measure, even quantitatively, especially since the results of exploring the upper atmosphere by means of radio echoes, as originated by our department in 1925, have become available. However, there is one really outstanding puzzle which all our knowledge of physics is still unable to explain, namely, the enormous permanent magnetic field of the Earth, which is about 94 per cent. of the magnetic field which acts on a compass and which is after all the thing we mean by terrestrial magnetism. We now have measured the deepest forces within the atom, we have, so to speak, chased magnetism all the way down to the smallest particles inside the atom, but we still have no clue as to why the Earth and the Sun have such large magnetic fields, each related in the same way to their directions of rotation. Perhaps some obscure atomic effect of the extremely high pressure at the centers of these large bodies may be the cause of the magnetization, but as yet we have no indication of why it comes about, and some new principle of physics may yet be required. It is more reasonable to believe, however, that the permanent magnetic field of the Earth is a problem of complexity which we as yet have no basis for calculation, rather than a problem of concept or fundamental idea. Almost certainly it will not require a revision of the well-authenticated laws of electromagnetic action, although some unexpected phenomenon, such as to constitute in effect a large electrical current inside the Earth, may ultimately be the explanation.

(D) Indirect Information Concerning Nuclear Forces

Mass defects: The hundred-year-old hypothesis of Prout, that all atoms are built up out of units essentially the same as hydrogen atoms, was placed on a firm experimental basis by the experiments of J. J. Thomson some twenty years ago, who showed that many (now most) of the chemical elements are each in turn mixtures of different species of atoms, separate species of the same chemical element, differing from each other by one unit of mass or weight. This unit is approximately the same as the mass of one hydrogen atom, although signicantly smaller.

Since the discovery of the neutron in 1932, a particle having very nearly the same mass as a hydrogen atom but with zero electrical charge and hence no attached electron to give it chemical properties, we have accepted the view that all nuclei are built up out of neutrons and protons, the proton being the nucleus of a hydrogen atom—a particle possessing an electrical charge exactly equal and opposite to that of a negative electron, and approximately 2,000 times as heavy as an electron. We may ultimately choose to consider that nuclei are built up of neutrons and positrons (positive electrons), a proton in the nucleus then being considered as dissociated into a neutron and a positron. At present this view appears to present so few possibilities of attack as to render it unripe for any theoretical formulation to be made, but it may well be true that protons lose their identity in the close confines of the nucleus. It is obvious that the problem of nuclear structure is one of inherent complexity and is correspondingly difficult to formulate, since we find that all nuclei have dimensions not very much larger than the protons and neutrons of which they are built—if we accept as the "sizes" of these particles the distances of separation at which large non-electrical forces become abruptly evident.

When protons and neutrons are bound together to form atomic nuclei an amount of energy is given off, in the form of radiation or otherwise, which is called the energy of binding, and since energy and mass are equivalent properties in accordance with special (restricted) relativity this binding-energy shows up as a loss of mass in the compound nucleus—its mass is smaller than the masses of the protons and neutrons which entered its structure by an amount which is an exact measure of the binding-energy—the energy that would have to be supplied from an outside source to again separate the nucleus into its component parts. This is called the "mass-defect," and it gives us an exact measure of the end-result, so to speak, of the actions of the nuclear forces. Mass-defects throughout the atomic table have been carefully measured, and they show one outstanding property of the nuclear forces, namely, that the energy of binding per particle is approximately constant throughout the atomic table, being roughly eight million electron-volts for each proton or neutron which enters the nuclear structure. This characteristic is referred to as "saturation" — whatever hypothetical kinds of nuclear forces we devise must therefore exhibit this property of saturation.

Nuclear transformations: A second source of information regarding the nuclear forces is the large body of data relating to nuclear transformations, or atomic transmutations ("atom smashing"), which has been built up since Rutherford's first demonstration of artificial transmutation in 1919, and especially since Cockcroft and Walton in Rutherford's laboratory first accomplished the same feat in 1932, using as bombarding particles protons which were accelerated by a high voltage applied to a vacuum tube—incidentally one of the possibilities envisioned when our department's high-voltage program was begun in 1926. The data on atomic transmutations give primarily a confirmation of the data on mass-defects. When a transmutation occurs with the evolution of energy (resulting in a loss of mass, a higher binding-energy) this energy appears frequently as kinetic energy of the resultant system of particles (one or several particles are emitted from the complex temporary system formed by the projectile and the target nucleus, leaving a residual nucleus which recoils as the particle is shot out). Measures of these large reaction-energies confirm the mass-defect data, but the measurements on nuclear transformations give one additional important kind of information. They determine the probabilities of various kinds

of reactions; they determine, so to speak, the rate of activity of the nuclear forces, and the degree of stability of various combinations or states of motion of the nuclear particles. This last remark is especially true because many of the products of reaction of nuclear transformations have only a limited stability, even though they are nuclei of the ordinary chemical elements and behave with perfect propriety in all chemical reactions. If a proton or a neutron is added to a nucleus to form a new nucleus which is one unit heavier or one unit lighter than the ordinary stable nuclei of the same chemical element as found naturally (I do not mean to imply anything "un-natural" about our alchemistic procedures), it is observed that the extra-light or extra-heavy nucleus "blows up" later. These nuclei explode in the same way as do the nuclei of the well-known radioactive elements at the heavy end of the atomic table—they possess a certain fixed probability which leads to the spontaneous emission of a negative or a positive electron during a given time. Accordingly, at the end of a period which varies from a fraction of a second to months or years, depending on the particular nuclear species, half of the unstable nuclei present at the beginning of the period have transformed themselves into a stable species of nucleus belonging to the adjacent element in the atomic table. This phenomenon is called artificial radioactivity, discovered by Irene Curie and F. Joliot in 1934[1]

High-voltage equipment and technique at the Department of Terrestrial Magnetism: Because some nuclear transformations are millions and even billions of times more probable than others the problem of unraveling the meaning of simple observations on the particles emitted by given targets under bombardment is not a simple one, since no targets are ever really chemically pure. It became clear early in our work that reliable conclusions could be obtained only by quantitative observations of the highest order, and in our first studies of artificial transmutations, from 1932 tc 1935, we concentrated our attention on the development of a technique adequate to deal with the problems to be met. I shall pass over this work with the remark that the quantitative yields of various reactions vary quite differently with voltage, and accordingly the most analytical technique is one in which the voltage or energy of the bombarding particles is under accurate control and is subject to accurate measurement. This includes, of course, the requirement that the bombarding beam must be very nearly homogeneous in kind and energy.

Our high-voltage source (Fig. 1) is an old-fashioned electrostatic generator charged by a belt, a device re-invented at an opportune time (1931) by Dr. R. J. Van de Graaff, then at Princeton University (the idea of belts for conveying the charge was proposed as long ago as 1870 by Lord Kelvin and by Righi, who constructed somewhat similar machines of small size at that time.) The high-voltage electrode is simply a ball of large diameter, following the standard electrical practice of preventing corona-losses by using electrodes of suitably large dimensions and small curvature (we used similar spherical "corona-caps" in all our experiments with Tesla coils and high-voltage tubes in the years 1926 to 1930). At the top of the vertical glass vacuum-tube, inside the 6-foot ball, is a small metal tube filled with a hydrogen (or heavy hydrogen) discharge at low pressure and low voltage (supplied by a small 110-volt generator driven by an auxiliary insulating belt). Protons or deuterons or helium ions (nuclei of light or heavy hydrogen or of helium, produced as ions in the low-voltage discharge) pass through a small canal from this discharge into the high-voltage tube. Here they are

[1] A demonstration of radio-sodium produced by deuteron bombardment (bombardment by the nuclei of heavy hydrogen) and of radio-copper produced by neutron bombardment accompanied the lecture.

focused as a beam, which is accelerated down the axis of the tube to strike a target placed in a grounded extension of the vacuum-tube which projects downward into the observing-room beneath the high-voltage generator. Before striking the target where the transmutations are to be produced this beam of high-speed particles passes through a strong magnetic field, which is so adjusted as to allow only ions of the desired kind to impinge on the target, for example, protons (mass one) or deuterons (mass 2) or helium ions (mass 4). This equipment produces a bombarding beam of great homogeneity in kind and energy (energy-spread under one per cent.) at any desired voltage from 200,000 to about 1,150,000 volts, and the voltage (energy of the particles) is measured accurately and continuously by a voltmeter-resistor (10,000 megohms, measurements to one per cent.) enclosed in the large Textolite tube shown projecting at an angle downward from the high-voltage "ball." The extent to which our technique meets the requirements demanded by the quantitative work I shall now describe on the proton-proton interaction is perhaps best indicated by the observations shown in Fig. 2. The data of this figure are measurements on the resonance-transmutations produced by protons bombarding fluorine; the individual observations are numbered in sequence, and the agreement of the different points, especially on the steep portions of the curve, is a good measure of the constancy of the beam and the accuracy of our voltage-measurements. Furthermore, the extremely sharp rise of the curve at each resonance is in itself clear-cut evidence of the homogeneity of our bombarding beam. Nuclear resonances of this type provide a convenient scale of voltage-calibration points which obviously will remain constant.

(E) Direct Observations on the Nuclear Forces

It is interesting that one of the stated aims of the high-voltage program of our department when it was begun in 1926, although not carried through until ten years had elapsed, nevertheless still proved to be of the highest importance in formulating definite ideas regarding the atomic nucleus. At that time we set ourselves the problem of obtaining measurements on the collisions of protons with protons to see whether deviations could be observed from the predictions based on the ordinary inverse-square law of repulsion between like electric charges. Deviations of this kind would be direct experimental information concerning the forces which had been assumed for many years to hold together the primary particles which were constituents of the atomic nuclei—the nuclear forces.

Neutron-proton scattering: I should remark that the first direct observations of the nuclear forces were observations of the scattering of neutrons by matter. If nuclei are built up of neutrons and protons as we believe, there are three forces active in the structure of the nucleus, namely, proton-neutron forces, proton-proton forces and neutron-neutron forces. The observation of the proton-neutron forces, by the scattering of neutrons by hydrogen, gave direct evidence regarding one of these three—the proton-neutron interaction—but the absence of knowledge regarding the other two left the problem in a state of uncertainty. Our measurements of the proton-proton interaction have given the second leg of the triangle, so to speak, thereby defining the third, and have led to the remarkably simple conclusion that all these three types of interaction are nearly, although not exactly, the same. This was shown by Dr. Breit's theoretical analysis of our experimental curves.

Proton-proton scattering: The experiments by which we have measured the forces between two protons at very close distances of separation are really very simple in conception; the difficulties have been only the difficulties of obtaining

adequately quantitative measurements on all the factors involved. Protons are accelerated to a specified velocity (energy) by the high-voltage tube and pass through a "window" of aluminum foil into the scattering chamber of Fig. 3, which is filled with pure hydrogen gas at pressure of 12 mm. The diaphragms at the top define a 2-mm beam of protons passing through the gas of the chamber, and protons scattered by "billiard-ball collision" from a small segment of this beam at the center of the chamber in such a direction as to pass through the set of diaphragms or slits fastened to the ionization-chamber (marked IC No. 1) are recorded as individual counts by a linear amplifier, similar to a radio amplifier. The loss of energy of the protons in the aluminum foil and in the gas is checked by measurements of the fluorine resonances (Fig. 2), using a target at the bottom of the lower tube, giving us accurate knowledge of the velocity of the protons at the scattering volume. The latter is defined by the intersections of the lines extended from the two diaphragm-systems. The ionization-chamber with its diaphragm-system can be set at various angles to the primary beam.

The observations comprise measurements of the number of individual protons which are scattered through various angles (from 500 to 10,000 at each angle) by the hydrogen (protons) in the small scattering volume when a known large number of protons of the primary beam passes through this volume. These numbers are then compared with the numbers which are expected on the basis of the electrostatic repulsion between protons, given by a formula due to Mott. The ratio of our observed numbered of counts to the number expected (for each given angle and voltage) gives a measure of the deviations arising from forces superposed on the Coulomb repulsion. Fig. 4 shows a series of such ratios for angles from 15° to 50° and for energies from 600,000 to 900,000 volts. If the inverse-square law were obeyed, all these curves would coincide with the dashed line drawn through the ratio of unity. It is obvious that in addition to the electrical repulsion between protons, some other force is acting and that this force is much more important at 900,000 volts and 45° than for lower voltages and angles. The protons come only slightly closer together in a collision at 900,000 volts than they do at 600,000 volts, so the additional force sets in quite abruptly when the protons come within a certain distance of each other.

The most direct evidence that this "extra" force is an attraction, and not an added repulsion, is perhaps that of Fig. 5, which shows the ratios of our observed counts to those predicted by the Mott formula for a 45° angle and for energies from 200,000 to 900,000 volts. It is seen that at 400,000 volts the observed scattering is nearly zero. This corresponds to a situation in which the repulsion due to the like electrical charges of the two protons effectively is just cancelled by the attraction due to the nuclear force acting between them. At 200,000 volts the scattering at 45° is primarily due to the electrostatic repulsion, diminished somewhat by the nuclear attraction, whereas above 700,000 volts the scattering at 45° is primarily a result of the nuclear attraction between the protons.

Two features of our experiments which are of importance from a quantitative standpoint have not been mentioned. One is the fact that a thin gold leaf is mounted in the tube below the scattering chamber, with a second counter set to observe the number of protons scattered by the gold. This arrangement gives us a continuous measure of the proton-current passing through the scattering volume—a measure, in other words, of the total number of primary protons involved in a given scattering measurement. The second feature is the method used to give an "absolute" calibration (centimeters,

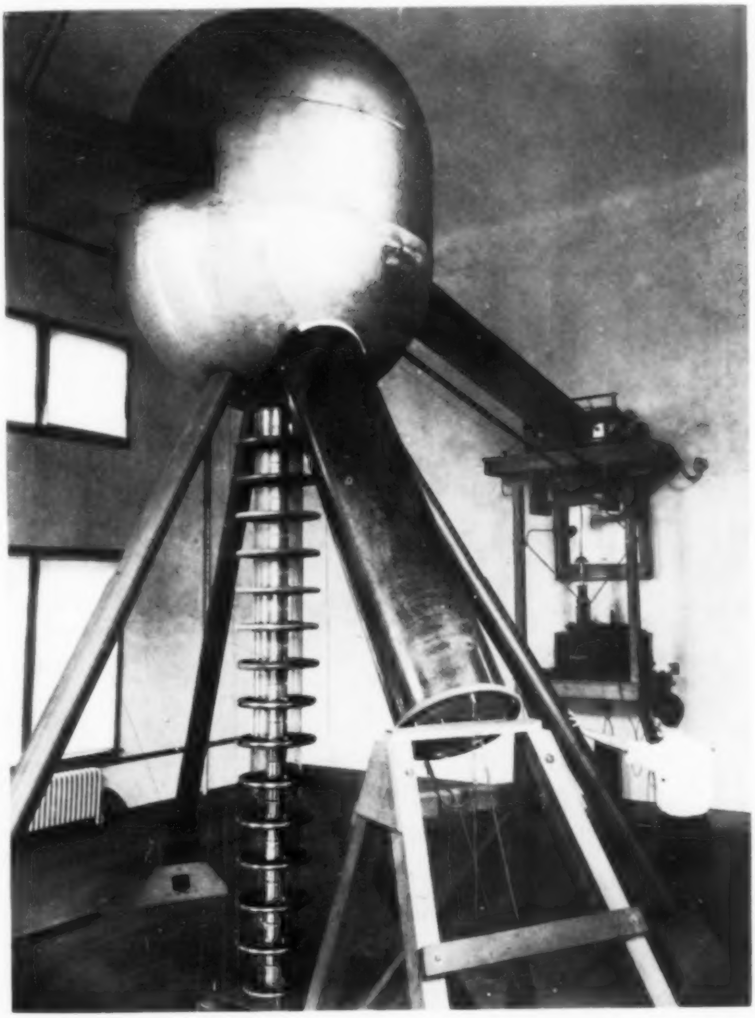


FIG. 1. THE 1,200,000-VOLT CONSTANT-POTENTIAL EQUIPMENT AT THE DEPARTMENT OF TERRESTRIAL MAGNETISM OF THE CARNEGIE INSTITUTION IN WASHINGTON. THIS EQUIPMENT HAS BEEN USED DURING THE PAST SEVERAL YEARS FOR STUDIES OF NUCLEAR TRANSMUTATIONS AND FOR DIRECT MEASUREMENTS OF THE LARGE FORCES WHICH BIND TOGETHER THE COMPONENT PARTS OF THE NUCLEI OF ATOMS. THE TARGETS AND OBSERVING INSTRUMENTS ARE IN A SEPARATE ROOM BENEATH THE HIGH-VOLTAGE EQUIPMENT SHOWN HERE.

grams, seconds) of the scale of our voltmeter. For this purpose we measure the number of protons scattered by a given small pressure of spectroscopically pure argon introduced into the scattering chamber. Since a nucleus of argon has 18 times as great a positive charge as a proton, the great repulsion between the nuclei of argon and the protons prevents the latter from approaching within range of the nuclear forces around the nuclei of argon, and the scattering is exactly "classical," that is, it follows the formulas based on the inverse-square law of electrostatic repulsion. This has been tested experimentally for various angles

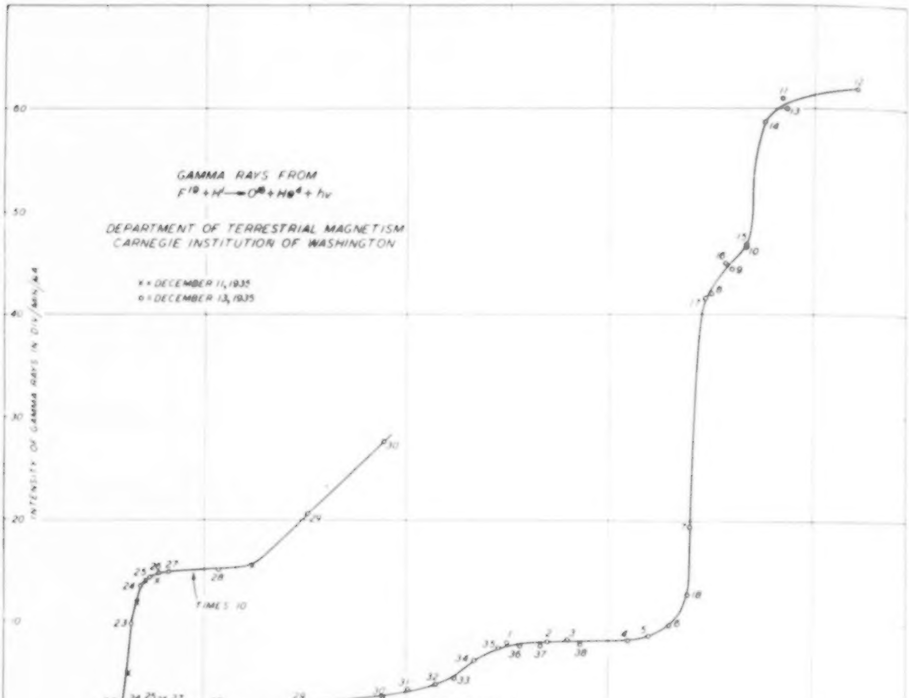


FIG. 2. MEASUREMENTS ON THE TRANSMUTATION OF FLUORINE BY PROTONS, PRODUCING OXYGEN AND HELIUM. THE STEEP PARTS OF THESE CURVES ARE EXAMPLES OF "RESONANCE"-TRANSMUTATIONS, AND PROVIDE EXCELLENT TESTS OF QUALITATIVE CHARACTERISTICS OF THE TECHNIQUE. THEY ALSO PROVIDE USEFUL REFERENCE-POINTS FOR CHECKING VOLTAGE CALIBRATION.

and voltages, using argon for the scattering gas (also using pure nitrogen and oxygen, which show very slight effects of the nuclear forces), with the result that we find it necessary to shift our original voltmeter-scale by somewhat less than 2 per cent. to give correct absolute values.

Direct conclusions based on the empirical evidence: From these data, then—and almost without reference to any form of theory regarding the nature of the nuclear forces—we are driven to the conclusion that when two protons are brought within a certain very close distance from each other a "new" force makes its appearance, superposed on the ordinary electrostatic repulsion between the two like charges of the protons. This new force sets in very abruptly and it is an attraction, which very rapidly overwhelms the large electrostatic repulsion and causes the protons to attract each other very strongly. This attraction is 10^{36} (1 followed by 36 zeros) times as large as the gravitational attraction between the two protons according to Newton's law, and in fact is about 10^{27} times as great as the weight of either proton. Small wonder that a high voltage is required to overcome the mutual electrostatic repulsion between charged particles when it reaches such a magnitude before the nuclear attraction comes into play! The "distance of approach" of the two protons for this range of nuclear attraction can not be spoken of with strict correctness, since the primary particles of matter are not mathematical points, but

have a certain diffuse (wave) character, but it is of the order of 5×10^{-13} cm. If a proton of this "size" is magnified to the size of a walnut, the atom of hydrogen would be several hundred feet in diameter, and the thumbs of the investigators who made these experiments would be more than ten million miles broad. On the same scale, the nuclear forces between the walnut-protons are not exhibited at all (under one per cent.) until they are brought within three or four inches of each other, the inverse-square law of electrostatic repulsion being perfectly obeyed for all greater distances of separation. Such a picture is too concrete, of course, to represent the cosmos of the atomic nucleus correctly, and should be viewed with a soft-focus lens for diffuseness, but it gives some idea of the degree to which these things are remote from our own scale of human dimensions.

(F) Atomic Characteristics of the Primary Physical Forces

Complexity versus basic concepts: The essence of scientific achievement or of what we may term understanding or knowledge or power over material things is the process of simplification, of reducing the apparent complexity of a whole collection of facts or experiences to a state of order in terms of a few basic ideas. This process of simplification has been carried out to an astonishing degree of completeness in describing the behavior of the physical world. The phenomena of chemistry and of molecular physics may be considered as expressions of the electromagnetic forces which act between atoms, and the laws of electromagnetic interactions as formulated in the wave-mechanics appear to be quantitatively valid, even when we concern ourselves with the mechanics of the interactions between various parts of the electronic structures of atoms. It is far from my intention to convey the idea that all the problems of molecular and chemical physics are solved—indeed most

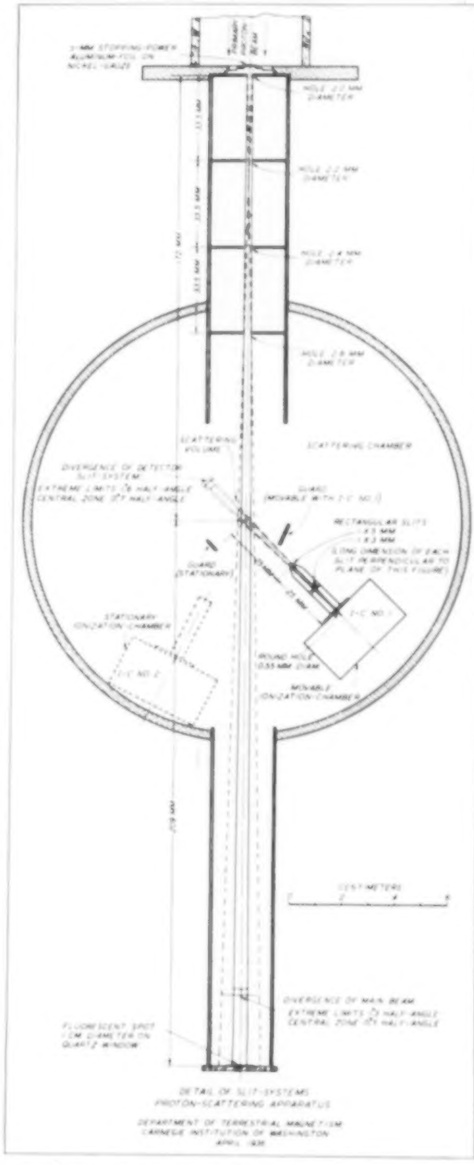


FIG. 3. DIAGRAM OF THE SCATTERING CHAMBER, USED FOR MEASUREMENTS OF THE LARGE NUCLEAR FORCE OF ATTRACTION WHICH WAS FOUND TO ARISE VERY ABRUPTLY WHEN TWO PROTONS (NUCLEI OF HYDROGEN) APPROACH VERY NEAR TO EACH OTHER.

of these will undoubtedly still be with us when we have reached satisfactory solutions of the problems which we call "fundamental," if in fact we ever do.

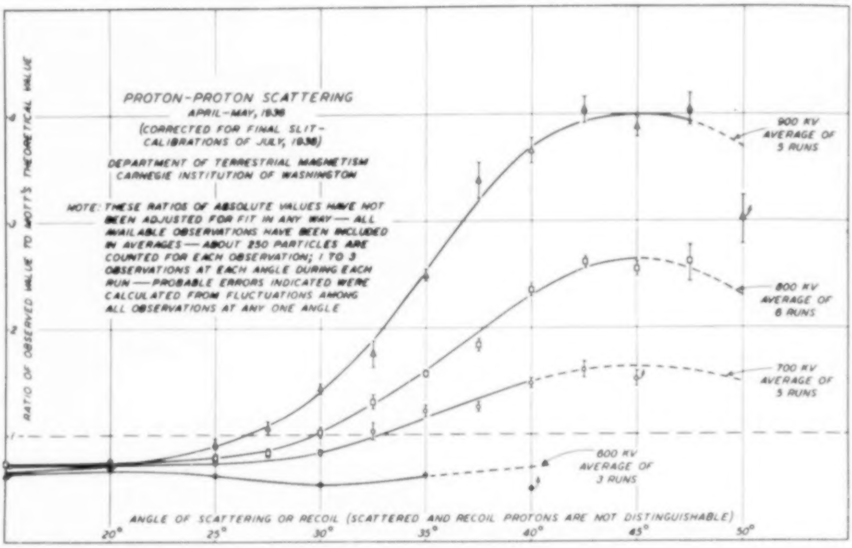


FIG. 4. RESULTS OF MEASUREMENTS ON THE ANGULAR SCATTERING OF PROTONS BY PROTONS ("BILLIARD-BALL COLLISIONS") AT ENERGIES FROM 600,000 TO 900,000 VOLTS. THE LARGE DEVIATIONS FROM THE VALUES EXPECTED ON THE BASIS OF THE ELECTRICAL REPULSION BETWEEN THE TWO PROTONS (EACH HAVING A POSITIVE CHARGE) SHOWS THE FAILURE OF THE FAMILIAR INVERSE-SQUARE LAW OF ELECTRICAL REPULSION DUE TO THE ADDITIONAL NUCLEAR ATTRACTION BETWEEN TWO PROTONS AT VERY CLOSE DISTANCES OF SEPARATION.

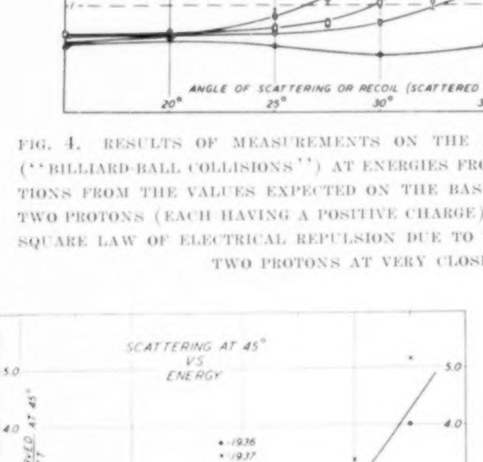


FIG. 5. MEASUREMENTS OF PROTONS SCATTERED TO 45° FOR A RANGE OF ENERGIES FROM 200,000 TO 900,000 VOLTS. AT LOW VOLTAGES THE PROTONS DO NOT APPROACH CLOSELY AND THE NUCLEAR FORCE HAS A SMALL EFFECT; AT 900,000 VOLTS THE EFFECT IS LARGE. THE ABSENCE OF SCATTERING AT 400,000 VOLTS IS DUE TO THE ELECTRICAL REPULSION BEING NEUTRALIZED BY THE NUCLEAR ATTRACTION. THE CURVE MARKED "THEORY" REFERS TO THEORY OF NUCLEAR FORCES, NOT THE CLASSICAL THEORY OF ELECTRICAL REPULSION WHICH PREDICTS POINTS ON THE DASHED LINE MARKED "$1/R^2$."

But difficulties of accounting in full for the detailed behavior of atoms in chemical reactions, for example, appear to us now as difficulties of *complexity* rather than as basic difficulties of *conception*. Although the picture and the words which accompany the formulas may quite possibly be changed again, as they so often have in the past as each new modification or refinement gave us a closer and closer approximation to the detailed and quantitative results of experiment, we are now inclined to believe that the laws of electrical and magnetic interactions as formulated in the wave-mechanics comprise a valid expression, although not necessarily a unique expression, of the essential laws governing molecular and chemical behavior, even though the mathematical complexities of a detailed treatment of the dynamics of the many-body problem will undoubtedly remain forever beyond our intellectual capacity.

When one stops to think, it is after all an exceedingly arrogant thing for a six-foot human being, with his five senses comprising the only routes of communication between his lone consciousness and the whole enormous, confusing, implacable, external world, to hope that he can arrive at *any* ideas or concepts sufficiently fundamental to encompass the behavior of all material things in a range extending from the smallest parts of the atom, a thousand-million-million times smaller than himself, to the most remote spiral nebulae he can observe with the 100-inch telescope, at a distance a billion-billion-million times larger than he is. This is quite without regard to the question whether the ideas he may arrive at are the *only* ideas having such properties. And it is perhaps a bit disturbing to realize the extent to which this arrogance seems to have been successful, viewing the scope and detail of modern physical science.

Let us turn, then, to a consideration of the three primary forces exhibited by matter, as indicated by Fig. 6. Gravitational forces are very small per unit quantity of matter, being of importance only when large amounts of matter interact with each other, as in astronomy. Even in engineering mechanics we neglect the gravitational attraction between the different parts of a building. As far as we know, or until we alter the meaning of the words "the force of gravity," the Newtonian forces are of no importance in atomics mechanics, being negligibly small in comparison with other atomic forces.

The electrical nature of matter: The electromagnetic forces are most common to our experience. As already remarked, all the forces of cohesion, impact, tension, compression, strength of materials, sound, light and chemical action are expressions of the electromagnetic forces between atoms and parts of atoms. During the last 40 years it has gradually been learned just what refinements of Maxwell's classical laws of electromagnetic interaction are necessary in atomic mechanics; in other words, refinements which become necessary in our analysis when we make it fine-grained enough to "see" the separate parts of atoms. These refinements or modifications are expressed in the quantum-theory in its modern form, called the wave-mechanics. As the word quantum indicates, one primary change or modification involves the introduction of an element of discreteness, limiting the infinite number of possible states of motion which might

GRAVITATIONAL FORCES	ELECTROMAGNETIC FORCES	NUCLEAR FORCES	
(NEWTON-EINSTEIN)	(COULOMB-MAXWELL)	Electron-neutrino forces (FERMI- ?)	
Emission of: Gravitational waves	Emission of: Light quanta (electromagnetic waves)	Emission of: β-rays and neutrinos	
Newtonian forces between masses $1/r^2$	Electric and Magnetic forces between charges $1/r^2$	A) "Ordinary" forces between heavy elementary particles (protons and neutrons) $1/r^2$?	No theory yet proposed. Difficulty: Inverse square law? No saturation of forces
----INTRODUCTION OF THE EXCHANGE PHENOMENON----			
Extremely small—not important	Chemical exchange forces e^{-r/r_0}	B) Exchange forces between heavy elementary particles (protons and neutrons) e^{-r/r_0}	Heisenberg and many others. Difficulty: Too small by 10^{12}

FIG. 6. CLASSIFICATION OF THE KNOWN PHYSICAL FORCES WHICH GOVERN THE BEHAVIOR OF ALL MATTER. AS INDICATED IN THE TEXT, THE FORCES WHICH GOVERN THE ATOMIC NUCLEUS ARE NOT YET WELL UNDERSTOOD, ALTHOUGH MANY OF THEIR CHARACTERISTICS HAVE BEEN DETERMINED BY EXPERIMENT.

occur to a finite series of steady states between which transitions occur, and atomic behavior corresponds to this discrete or discontinuous type of electromagnetic action. In any large-scale problem, however, the quantum-theory degenerates or irons out into the familiar electromagnetic laws.

The other primary modification of classical electromagnetic theory which has been found necessary in dealing with the mechanics of the outer structure of the atom is the introduction of the idea of the wave-nature of matter, as expressed in the modern form of the quantum-theory called the wave-mechanics. This formulation of the quantum-theory, developed since 1925, treats all material particles as "wave-packets." We need not concern ourselves here with the nature of matter-waves beyond saying that when we go down to the scale of atomic dimensions the simple picture of the various particles of matter as mathematical points has turned out to be inadequate, they are endowed with certain wave-characteristics, and the equations developed on this wave-basis, using the electromagnetic forces, have been almost completely successful in dealing with the previous difficulties encountered in the electromagnetic theory of the interactions between atoms and in the outer structures of atoms. The forces in a crystal lattice, forces of chemical interaction, the conduction of electricity in metals, electron-diffraction, atomic and molecular spectra, ferro-magnetism and similar problems are examples of its success. These basic ideas of wave-character and quantization or discontinuity, as incorporated in the formation of the wave-mechanics, have also proved successful to at least a considerable extent in treating the mechanics of the nuclear forces, which are by no means necessarily electromagnetic, and in fact may as well be considered at present as intrinsically non-electrical. The old hypothesis that matter is entirely electrical in nature, that the mass of a particle is simply the inertia of its electromagnetic field, is now a question of little interest, being at best largely a matter of words; most of us would prefer not to enlarge the word "electrical" to include everything we now know.

Exchange-forces: The exchange-phenomenon, referred to earlier, gives rise to what we call exchange-forces and is a sufficiently new and important addition to our ideas of the structure of matter to merit a brief description. The phenomenon of exchange refers to the necessity for us to take into consideration certain effects which arise from the fact that our atomic parts are similar. The importance of this exchange-phenomenon arises from the fact that, according to the wave-mechanics, atomic parts are not just mathematical points, but extend somewhat diffusely through a region of space which has a size greater than zero, and hence may overlap each other.

Referring to Fig. 7, we may inquire what happens when an atom with its normal atmosphere of electrons approaches a similar atom which has lost one or several of its outer electrons, forming what we call an ion. On the classical picture the orbits of the electrons are disturbed by the electrical attraction of the ion and a polarization of the normal atom occurs as it approaches the ion, giving rise to an extra attraction between them which varies as the fifth power of the distance between the two atoms, even on the basis of the inverse-square law of force between all the charged particles concerned. Using this picture, however, sharing or interchange of electrons between the two atoms can not occur until the atoms are so close together that the hills or barriers of electrical potential surrounding the atoms coalesce sufficiently to permit the electrons held by one atom to wander over to the other atom without climbing out of the "potential hole," which represents the energy of attraction of the

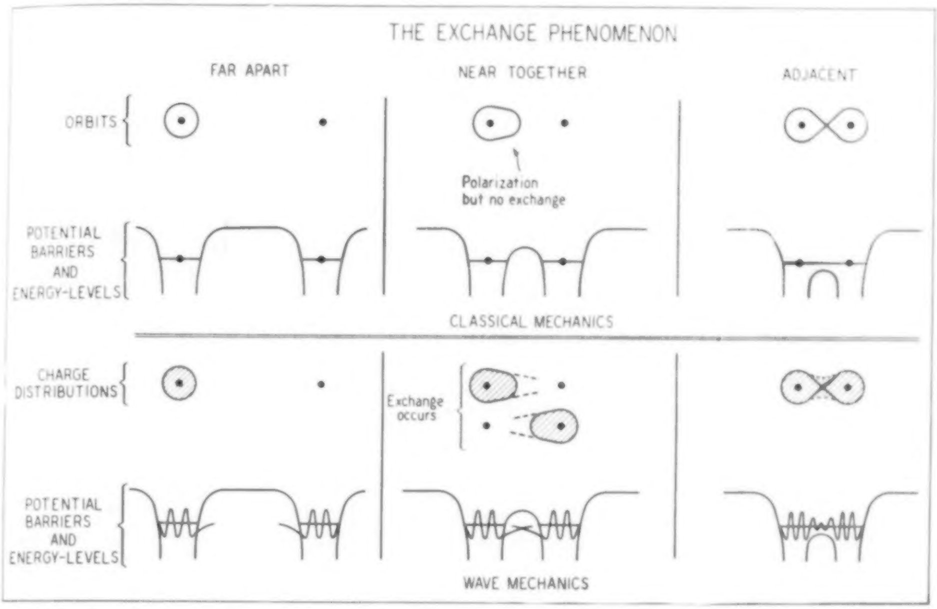


FIG. 7. DIAGRAM ILLUSTRATING THE "EXCHANGE-PHENOMENON" WHICH GIVES RISE TO FORCES BETWEEN ATOMIC PARTS WHICH WOULD NOT BE EXPECTED IF THESE PARTS BEHAVED AS PARTICLES OF ZERO-SIZE. AN IMPORTANT CONDITION IS THE FACT THAT NO TWO ATOMIC PARTS CAN SIMULTANEOUSLY HAVE THE SAME "QUANTUM-NUMBERS" (WHICH SPECIFY POSITION, VELOCITY AND ORIENTATION).

electron to an atom. The normal energy of a given electron attached to an atom is represented by an energy-level inside this potential hole, as shown in Fig. 7. On the wave-mechanics, however, there is a certain "leakage" of the matter-waves which correspond to the electrons of one atom passing directly *through* the potential hill or barrier between the two potential holes. Thus an electron can be exchanged between the two atoms *before* they are so close together that their potential holes, or spheres of attraction, coalesce. Such an exchange is of importance only if the energies of the two cases are similar, so that *resonance* occurs. The forces between the two atoms, even though they may be considered intrinsically as electrical forces, depend then not only on their distances apart, based on the inverse-square law, but on this phenomenon of exchange of charges, which gives rise to an additional energy-term in the equations, corresponding to the particles exchanging their charges when they are near to each other, with a certain frequency. It is exactly this type of exchange which is responsible for what we call the chemical forces, which are interactions between the outer parts of atoms which cause them to associate together and form chemical compounds. All atomic particles furthermore are endowed with intrinsic spin or angular momentum, and the exchange of spin can give rise also to a similar additional force. These extra forces are called *exchange-forces*, and they may be attractions or repulsions, depending on specific conditions.

In this connection, there is one requirement which is of fundamental importance, and which operates to give large effects dependent upon exchange. This is the law—called the Pauli Principle—which states that if two particles in an atomic system are not only similar but are indistinguishable, or identical in all

their properties, they can not both be in the same "quantum-state"—they can not have the same position, velocity and orientation. If more than one electron, for example, takes part in exchange, this law exercises a regulatory function with regard to the states which the several electrons can occupy, and thus may determine whether attraction or repulsion will arise. When particles are identical in this way, they may exchange their places and properties without actually changing the system under discussion in any way we can tell. The atomic parts have no serial numbers.

The nature of the forces inside atomic nuclei: We are accustomed to thinking of these exchange-forces between atoms as simply additional attributes of electromagnetic forces which arise when the analysis is made fine-grained enough to deal with atomic dimensions, although one may quite properly say that this identification is somewhat arbitrary. In an arbitrary way we might also consider the forces inside the nucleus to be further large modifications of the ordinary electromagnetic forces which apply to these still smaller regions of space inside the nucleus. For that matter we might equally well consider them as enormous modifications of the law of gravitation setting in abruptly at very short distances between massive particles, but the nuclear forces are so tremendously large and set in so abruptly at very short distances that it seems less arbitrary to regard them simply as another kind of force, obeying, however, the same requirements of fundamental discreteness and exchange as were found necessary in the quantum-theory or wave-mechanics obeyed by the electrically charged particles forming the outer structures of atoms. In addition, since the nuclear particles to a certain degree possess electrical charge and magnetic moment, the electromagnetic requirements of the wave-mechanics are imposed to the same degree on the nucleus, in respect to the radiation of electromagnetic waves (gamma rays), for example.

"Understanding" the nuclear forces: Fig. 6 also indicates briefly the status of our theoretical understanding of the nuclear forces. We know that the nature of these forces is intimately tied up with the phenomenon of the emission of beta rays, which are electrons (positive or negative) shot out of radioactive nuclei with a continuous distribution of energies. Fermi has made an attempt to explain the forces between the heavy particles in the nucleus as arising from exchange-interactions of the electrons and neutrinos associated with the heavy particles. Using the data available, however, these forces appear to be a million-million times too small to account for the known energies of binding of nuclei. The shape of the energy-distribution of the beta rays predicted by this theory furthermore does not agree with the observed distribution, although this difficulty may not be insoluble if the Fermi forces are made more complicated than one might like by the introduction of various derivatives of the functions used. Numerous modifications of the exchange-phenomenon have been considered, following the example of Heisenberg, involving exchange of charge, exchange of spin, exchange of both charge and spin and even the exchange of pairs of charges. None of these formulations appears satisfactory. At present there is no experimental evidence of great weight which shows that the forces inside the nucleus are specifically of the exchange-type or even largely so, but we all are inclined to believe them to be of this type, chiefly because forces of an "ordinary" type (derivable from a potential) do not exhibit the property of saturation. This refers to the fact, as you recall, that each particle added to a nucleus is bound to the rest by a total energy which is about the same, per particle, throughout the atomic table. With ordinary forces each particle interacts

FIG. 8. VIEW OF THE COMPLETED ATOMIC PHYSICS OBSERVATORY AT THE DEPARTMENT OF TERRESTRIAL MAGNETISM OF THE CARNEGIE INSTITUTION IN WASHINGTON.

individually with each other particle already present, and the energy of binding for adding another particle should be much larger if the initial nucleus contains many particles than if it contains only a few. Consequently, if one wants to keep the idea of ordinary potential forces, it will be necessary to assume forces which do not act independently between pairs of particles, but which actually are determined by the number of particles present. In this case the interaction between a pair of particles is itself altered when a third particle is added to the system.

I should remark that our experiments on proton-proton scattering exhibit a definite deviation in the variation with

angle which is roughly in agreement with the assumption of exchange-forces. Our curves show a deviation (about 10 per cent. excess scattering at 20° angle) from the curves which would be expected on the basis of nuclear theory for the simplest kind of scattering (spherically symmetrical), and this deviation has the sign (indicating a slight added repulsion) which is expected if exchange-forces are acting. The major features of the proton-scattering measurements, however, and of neutron-proton scattering measurements as well, are just as would be expected if an ordinary potential-well exists, giving rise to a strong attraction. Except for differences of detail, they do not indicate whether or not this potential-well represents exchange-forces instead of an ordinary potential. Exact and very comprehensive proton-scattering measurements over the voltage range from 0.2 to 5 million volts—or the fortunate future discovery of outstandingly characteristic proton- or neutron-scattering anomalies at higher voltages—may be expected to remove these present uncertainties as to the exchange-nature of the nuclear forces.

Intimately a part of this problem of the nuclear forces is the apparent lack of conservation of energy in the emission of continuous beta-ray spectra by radioactive nuclei (those which spontaneously

FIG. 9. STEEL TANK 55 FEET HIGH BEING BUILT TO HOUSE THE LARGE NEW EQUIPMENT FOR NUCLEAR-PHYSICS RESEARCH. ELECTRICAL INSULATION IS PROVIDED BY DRY AIR COMPRESSED TO 50 POUNDS PER SQUARE INCH IN THIS TANK. THE OBSERVATION-ROOM IS UNDERGROUND, TO GIVE EASE OF SHIELDING AGAINST INTENSE NEUTRON AND GAMMA RADIATIONS.

change from one chemical element to another by the emission of positive or negative electrons). The initial and final nuclei presumably being the same whether a fast or a slow electron is ejected, one must account for the apparent disappearance of some energy when the beta ray is a slow one. Physicists have "solved" this problem by inventing a new particle of mass equal or nearly equal to zero, the "neutrino," whose chief property is the ability to carry off this energy without detection—almost, in fact, without possibility of detection, since it has no other definite property except angular momentum or "spin" (without magnetic moment). Whether or not the neutrino can ever be more than a name for a difficulty depends on its being endowed either by theory or by experiment with more properties than it yet can be said to possess, thus showing its interaction with matter and making its presence known.

Another aspect of this general problem is the formulation of a concept of the detailed structure of a nucleus; at present it appears, as Bohr has emphasized, that this problem may remain permanently hopeless of detailed solution, since the sizes of nuclei are not much greater than the "sizes" of the particles of which they are composed, bringing us abruptly to a stop at the solid wall of difficulty presented by the detailed many-body problem. One further difficulty we meet at once in the nucleus is the present lack of a relativistic equation for the proton or neutron, something like the Dirac equation for electrons. Being unable to formulate a proper relativity-correction appears currently to be a serious obstacle in the way of any efforts toward a sound interpretation of the minor quantitative details of our proton-proton scattering measurements, for example. The interaction of the primary constituents of matter at still higher energies is also a logical extension of the problems encountered in the nucleus. In the region of cosmic-ray energies, certain facts about electrons and radiation appear to be established, but for the most part our ideas are subject to a large degree of uncertainty.

It is thus clear that our difficulties in understanding the forces which govern the atomic nucleus, now that we have begun to acquire a considerable fund of information about them, constitute very much of a fundamental problem in physics in the sense which I have indicated above—a failure of our concepts, a lack of a workable pattern for our thinking. It is also clear, many of us think, that the most hopeful direction for our efforts in seeking a solution of these difficulties is the extension of our quantitative experimental data on two-body heavy-particle interactions (proton-proton and proton-neutron), especially toward higher voltages, and the accumulation of similar data on the beta rays. The chemistry of nuclear reactions has its own intrinsic and conceivably practical interest, but acquiring exact data on interactions which are essentially simple, or at least as simple as possible (the beta rays always involve more than two primary particles), appears to offer perhaps the greatest likelihood of giving us a proper conceptual basis for understanding this microcosmos of atomic nuclei which surrounds us wherever we turn.

(G) Postscript—The Atomic Physics Observatory

This general discussion of our interest and work at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in the field of nuclear physics can hardly be concluded without making brief reference to the new high-voltage equipment the institution is now providing the department for extending our investigations along these lines. Fig. 8 is an exterior view of the new installation, which has been named the "Atomic Physics Observatory." The equipment comprises a steel tank 55 feet

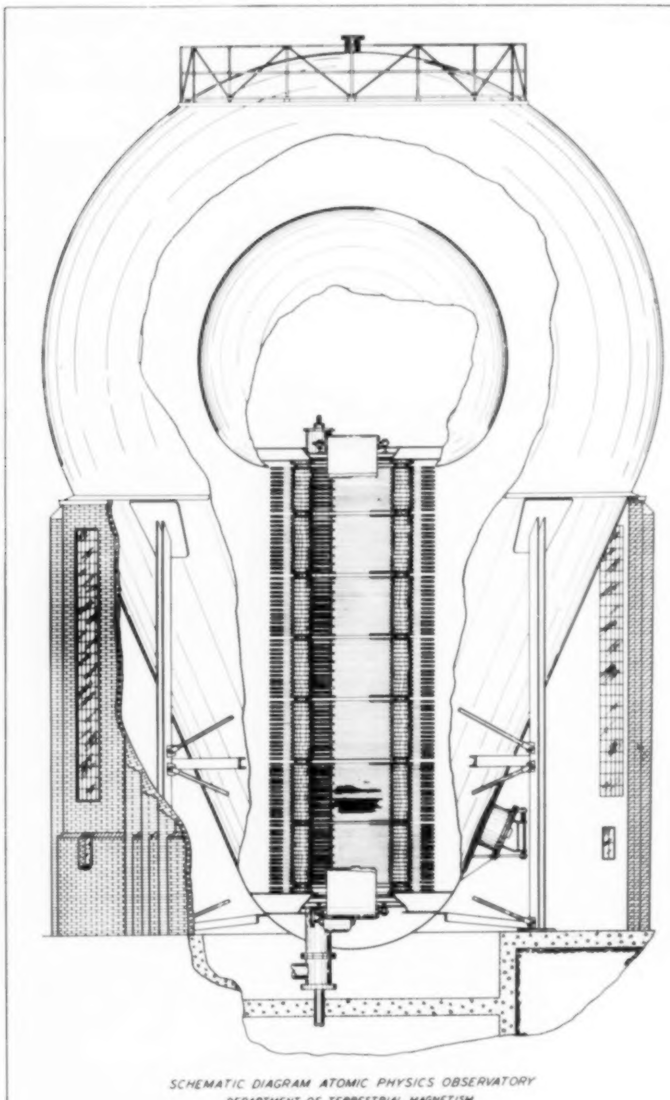


FIG. 10. SCHEMATIC DIAGRAM SHOWING THE INTERNAL CONSTRUCTION OF THE NEW 5,000,000-VOLT EQUIPMENT. THE TARGETS AND OBSERVING INSTRUMENTS AT THE BOTTOM ARE OMITTED. THE STEEL BALL SHOWN INSIDE THE TANK CAN BE CHARGED TO ANY DESIRED POTENTIAL UP TO 5,000,000 VOLTS. PROTONS, ELECTRONS OR OTHER BOMBARDING PARTICLES RELEASED AT THE TOP OF A LARGE VACUUM-TUBE REACHING INTO THIS BALL ARE ACCELERATED BY THIS POTENTIAL DOWNWARD TO TARGETS IN A ROOM BELOW THE STRUCTURE SHOWN. THE HIGH-VOLTAGE BALL IS 19 FEET IN DIAMETER AND IS SUPPORTED ON PORCELAIN COLUMNS 26 FEET HIGH.

high and $37\frac{1}{2}$ feet in diameter, containing an electrostatic generator and vertical high-voltage tube, insulated for constant and accurately controllable potentials up to five million volts (and perhaps higher) by dry air at pressures up to 50 pounds per square inch. The electrical power of the generator is of the order of ten kilowatts. Beneath the tank is a target-room, completely underground (giving ease of shielding of personnel and instruments from the powerful intensities of gamma rays and neutrons), connected with our present high-voltage laboratory by a tunnel.

It is of some interest to remark that perhaps the most formidable technical problem encountered in the design of this equipment has been that of providing a suitable mechanical support for the 5-ton steel "ball," 19 feet in diameter, which is the high-voltage electrode, and which is supported on the outside tank (which moves slightly in the wind) and contains belts and other vibrating and energetic machinery. This ball had to be supported 26 feet above the base-platform on fireproof insulating columns (compressed air gives increased risk of fire), preferably of porcelain, which has notoriously bad mechanical properties in bending or tension. We therefore adopted a support design which is like a stack of seven flat-steel table-tops, each spaced from the next higher by four stubby legs of porcelain; the porcelain in this way is never subjected to anything except stresses of compression.

Fig. 9 shows the large tank, built by the Chicago Bridge and Iron Company, in process of erection. Fig. 10 shows a schematic design of the internal equipment, now in process of assembly (March, 1938). The architectural engineering was handled by Messrs. Norcross, Corning and Elmore, of Washington, and the building and concrete work by Mr. Raymond Burrows, contractor.

In conclusion, I must endeavor to express the profound gratefulness of my colleagues (Drs. Hafstad, Heydenburg and Breit) and myself to Dr. John C. Merriam, president of the institution, and to our colleague and director, Dr. John A. Fleming, for their generous and patient support of our efforts during the years we have been engaged on this program.

A UNIQUE STATION FOR BIOLOGICAL RESEARCH IN THE TROPICS[1]

By Dr. R. E. COKER

CHAIRMAN OF THE DIVISION OF BIOLOGY AND AGRICULTURE, NATIONAL RESEARCH COUNCIL

For hundreds of years the Tropics have served as a particularly potent lure to leading biologists in all parts of the world. It is not the result of mere chance that, to most of us, pictures of tropical regions have represented the embodiment of our conception of primeval conditions of life. Of course primeval conditions were not necessarily "tropical," but it is the torrid regions of the surface of the earth that of all terrestrial areas have most successfully resisted the encroachment of civilized man with the modifications of "natural" conditions that have inevitably marked his coming. That the high seas are undominated by man is attributable not so much to the biological conditions as to the physical conditions which make such areas impossible for permanent occupancy. With the Tropics, on the other hand, man meets not only the resistance of physical conditions, which are more easily overcome, but also that supreme luxuriance of plant and animal life which not only obstructs the initial invasion but also by guerilla tactics makes virtually impossible the effective consolidation of any extensive area of invaded territory. There we have manifested to the highest degree the forces of organic pressure which have generally prevented either the development of an advanced civilization or the long endurance of one that may have met temporary success against almost insurmountable conditions.

[1] The "author's" part is rather that of an editor availing himself freely of materials from the annual reports of Dr. Barbour and Mr. Zetek and the notes of Dr. I. F. Lewis, past chairman of the Division of Biology and Agriculture, National Research Council.

The Tropics are therefore the most favorable place for the study of a great diversity of both primitive and highly specialized types of plant and animal life and for inquiry into the conditions of animal and plant life in states almost entirely unmodified by human influence. Stark competitive conditions prevail, but the competition is between individuals and societies of animals and of plants rather than between wild animals and plants as opposed to relatively ineffective man. Few, if any, biologists who have attempted to carve a temporary path through the rich jungles, who have faced the prolific manifestations of plant and animal multiplication and evolution, who have contemplated the bewildering display of color, size and forms in fauna and flora, and who have given ear to the impressive alternations of silence and animal orchestration, have failed to derive an enduring intellectual stimulus.

Geographers will readily assure us that it is due to no accident that a populous and allegedly prosperous nation has developed in a strictly temperate region of the northern hemisphere. The United States has one, and only one, tropical continental possession, and that is the Canal Zone, but for its domination it proved necessary to modify laboriously and expensively the original natural conditions. It was not the physical difficulties encountered in Panama that so long baffled and effectually stalled the efforts to make a connecting waterway between the Atlantic and Pacific through the Isthmus of Panama. The real obstacles to be overcome were primarily biological and, as is universally recognized, it was

BARRO COLORADO ISLAND BIOLOGICAL STATION, SHOWING PORCH OF MAIN LABORATORY BUILDING; DR. BARBOUR'S HOUSE TO LEFT IN WOODS; MR. ZETEK'S OFFICE TO THE RIGHT; HOUSE FOR ELECTRIC GENERATOR IN FOREGROUND UNDER BIG COCONUT PALM.

the biological developments of the early part of the twentieth century rather than advances in engineering that made possible the building of the Panama Canal.

The Canal Zone itself is a narrow and extremely modified tropical area, but it embraces a remarkable island—a body of land that is insular in a double sense. Topographically, a formerly prominent forested headland now emerges from the surface of a large artificially formed lake as a true island in the physical sense. Biologically, this body of land, some three and one half miles in diameter, is a floral and faunal island, to be perpetuated as such since it was officially designated by Governor J. J. Morrow in 1923 as a national park, to be reserved for scientific uses. In 1924 the island became the home of a research establishment under the auspices of the Institute for Research in Tropical America, then an agency of the National Research Council. Although this laboratory has at times led a precarious life, it has continued to exist, to develop healthfully and to serve as a unique and highly useful institution for tropical research, chiefly because of the unfailing interest and unflagging support of Dr. Thomas Barbour, chairman of the executive committee of the institute, and the consistent and invaluable volunteer service of Mr. James Zetek.

Barro Colorado Island, with an area of about six square miles, has a maximum

WILLIAM MORTON WHEELER TRAIL.

SLOTHIA ISLAND AND LAKE FROM LABORATORY, MAINLAND BEYOND.

elevation of 452 feet above the surface of the lake. Almost entirely wooded, it is surrounded by Gatun Lake, with a shore line of more than 100 miles and hundreds of bays and inlets, fed by the Chagres and Gigante Rivers. It possesses the highly advantageous qualities of being accessible at no great expense, having an excellently equipped laboratory with an administration hospitable to all interested and qualified scientists and harboring undisturbed fauna and flora in great diversity and abundance. The natural conditions are indeed modified only by the provision of the necessary laboratory, living quarters, landing docks and the trails necessary to give access to the various parts of the reservation on which studies may be pursued.

Among the forms of animal life on the island are 250 species of birds and 53 species of mammals, including opossums, sloths, anteaters, armadillos, peccaries, deer, tapir, agoutis, squirrels, raccoons, coatis, ocelot, bats, capuchin monkeys, night monkeys and black howlers, to say nothing of insects too numerous to mention.

Accessible from the laboratory as headquarters are the tropical forests of Panama and particularly the new Forest Reserve in the Canal Zone—"A singularly beautiful area of really good luxuriant forest, lots of interesting plants, birds, insects, etc., and a chance to see the old 'gold road' which originally ran from old Panama to the head of navigation in the Chagres River at Las Cruces—for the new concrete road cuts directly across this, the oldest road on the American continent—indeed the original cobblestone paving can plainly be seen. . . ." In this Reserve, set aside by Colonel Harry Burgess in 1930, are walks from which one can not get lost and from which a lot of tropical wild life can be observed.

Although unfortunately the institution has never enjoyed the assurance of permanent financial support, it has already

acquired a notable history in service to scientists of diverse interests and in biological productivity, as evidenced by the extended list of publications made possible wholly or in part through research conducted in or from the Barro Colorado Island Biological Station in the Panama Canal Zone. The number of published papers now credited to the laboratory—and the list must unfortunately and unavoidably be incomplete—now totals 316, or an average of more than twenty-two per year. Besides yielding reports of mainly technical interest the laboratory

"MY TROPICAL AIR CASTLE," OF FRANK M. CHAPMAN.

INLET ON NORTH SHORE OF BARRO COLORADO ISLAND.

has contributed its part to such books of popular appeal as Standley's monograph on the "Flora of the Panama Canal Zone," Sturgis' "Field Book of Birds of the Panama Canal Zone," Chapman's "My Tropical Air Castle," Snyder and Zetek's "Termites and Termite Control" (two chapters contributed to the volume published by the University of California), Weston's "Fungi of Barro Colo-

ROOF OF THE JUNGLE FROM THE LOOKOUT ON HIGHEST POINT OF THE ISLAND.

rado,'' Carpenter's ''Field Study on the Behavior and Social Relations of Howling Monkeys,'' Bailey's ''Palms of Panama,'' Rau's ''Bees and Wasps'' and Schneirla's ''Studies on Army Ants in Panama.''

The list of names of those who have worked in this laboratory constitutes an impressive register of contemporary biologists interested either in tropical science or in biological research for which material must be sought in tropical regions. Among such are W. C. Allee, Frank M. Chapman, O. F. Cook, F. E. Lutz, Maynard M. Metcalf, George H. Parker, Alexander Petrunkevitch, Franz Schrader, W. H. Weston, W. M. Wheeler, G. B. Wislocki, L. L. Woodruff and Robert M. Yerkes, to cite only a few names typifying a diversity of biological fields of activity. Even more impressive is the great number of letters from former table occupants containing expressions of grateful and even enthusiastic appreciation of the courtesies and facilities extended to them and the effective aid rendered to their efforts in research.

Such is the one tropical biological research station maintained under the American flag and at present supported only by table subscriptions from eight institutions,[2] the modest fees from visiting scientists and voluntary contributions from a limited number of personal friends of the laboratory. Universities, biological societies, other institutions for the advancement of biological research and biologists in general may well be interested and concerned with the future of so valuable an agency for biological science.

[2] The following institutions supported the island through table subscriptions in 1937—Smithsonian Institution, Dartmouth College, Harvard University, Yale University, New York Zoological Society, Carnegie Institution of Washington, University of Chicago and the American Museum of Natural History. Northwestern University will resubscribe for 1938, and also the University of Michigan.

DR. ALBERT EINSTEIN
PHOTOGRAPH TAKEN ON JUNE 6, WHEN HE GAVE AN ADDRESS AT SWARTHMORE COLLEGE.

THE PROGRESS OF SCIENCE

THE BUILDINGS OF CAMBRIDGE

At the meeting of the British Association for the Advancement of Science, held in Cambridge from August 14 to 24, a forecast of which was given in the September issue of THE SCIENTIFIC MONTHLY, arrangements were made for closer cooperation between the British and American associations. There will be an annual exchange of lecturers at the meetings of the two associations and there will be honorary representatives of each association on the governing body of the other. There were nearly a hundred Americans at the Cambridge meeting, the largest number in its history, doubtless in part attracted by a meeting at the university which has so greatly contributed to the advancement of science in England.

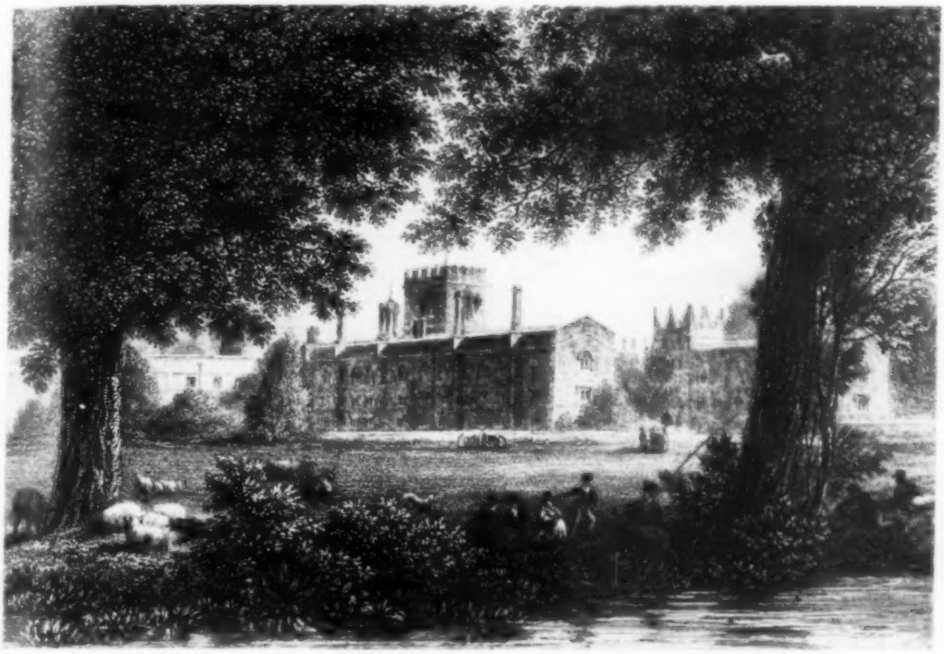
Not a little of the unique charm and beauty of the University of Cambridge springs from the variety in architecture and the widely variant historical background of its storied buildings. No building of the university is without its own richly colored tale, now historical, with its roots buried in a past incredibly remote to American eyes, now as modern as research in nuclear physics. From the days of the founding of St. Peter's College by Hugh de Balsham, Bishop of Ely, in 1284, and of Clare College in 1326 by Lady Elizabeth, granddaughter of Edward I, to the erection of the new chemical laboratory and the newly constructed laboratory of experimental physics with its elaborate facilities for high voltage research, exists an unbroken span of academically eventful and pro-

Etching by R. Farren.

PETERHOUSE, THE OLDEST OF THE CAMBRIDGE COLLEGES

Etching by A. Brunet-Debaines.

THE CAM NEAR TRINITY COLLEGE, WITH THE TOWER OF ST. JOHN'S COLLEGE CHAPEL



Engraving by J. LeKeux.

JESUS COLLEGE. FROM THE MEADOWS

ductive years. Epochs can be dated by the colleges which they brought into being, as the loosely organized system of unofficial hostels which obtained in the twelfth and thirteenth centuries gradually crystallized into the system of colleges as we know them to-day. Pembroke Hall in 1347, King's College in 1441, Queen's College in 1448, and Trinity College in 1546, served as landmarks of the passing of centuries, and between them came all but four of the remaining colleges of the university. Each added its own unique contribution to the community on the Cam. How early the organization program of the colleges was established in essentially its present form is indicated by the fact that only two, Downing College, founded in 1800 by Sir George Downing, and Selwyn College Public Hostel, founded in 1882 in memory of George Augustus Selwyn, late bishop of Lichfield, have appeared since the coming of Sidney Sussex College in 1596.

A very ancient group of colleges, connected with a university yet more ancient, may still be surrounded with buildings very variable in age and style. No building of the University of Cambridge is more important than its library. Over 800,000 volumes and 10,000 manuscripts are housed in the university library, whose spacious construction and lighting fit it admirably for a study as well as for a home of books. Here is kept the precious *Codex Bezae*, consisting of a copy of the Four Gospels and the Acts of the Apostles. It was presented to the university in 1581 by Theodore Beza, and is believed by Scrivener to have been derived from an original dating not later than the third century.

No less famous than the university library is the Acton Library, presented by Viscount Morley in 1902 and containing 59,000 volumes. It is entitled by the copyright act to a copy of every book published in the United Kingdom,

Etching by R. Farren.

THE FIRST COURT, SIDNEY-SUSSEX COLLEGE

and large sums are spent in the purchase of foreign books each year.

The Fitzwilliam Museum, with its collections of paintings, coins and ancient marbles, is one of the more striking members of the university grouping. The museums and laboratories of science cover much ground near the center of the university. They were formally opened by King Edward in 1905. Inconspicuous in its setting as it is great in its place in world science, the Cavendish Laboratory of Experimental Physics, whose new director, Professor W. L. Bragg, has but very recently come from the National Physical Laboratory to take up his post, faces on Free School Lane. Outwardly, it is almost crowded from the street by the pressure of the buildings around it, but within evidences of the work of Maxwell, Rayleigh, Thomson, Rutherford and other world figures who have contributed to its name speak for themselves.

In its buildings, no less than by the work done in them, the University of Cambridge need take second place to no other educational institution in the world.

CARYL P. HASKINS

CHEMISTRY AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY

THE new Crellin Laboratory of Chemistry has been opened at the California Institute of Technology. It is the gift of Mr. and Mrs. Edward W. Crellin, of Pasadena, whose interest in the work in chemistry at the institute was initiated through their friendship with Mr. Charles W. Gates, one of the donors of the Gates Laboratory of Chemistry, built in 1916.

The Crellin Laboratory, which is adjacent to and connected with the Gates

Laboratory on one side and the new Kerckhoff Laboratory of the Biological Sciences on the other, has three floors above ground, each about 60,000 square feet in area, and in addition a basement and sub-basement. The building contains two classrooms and three laboratories for undergraduate instruction in organic chemistry; aside from these rooms, it is devoted entirely to graduate study and research. The second and third floors are equipped for research in organic chemistry, including especially the chemistry of substances of biological significance, and the first floor, basement and sub-basement are to be devoted to research in physical chemistry and structural chemistry, including photochemistry, magnetochemistry, spectroscopy and x-ray and electron diffraction.

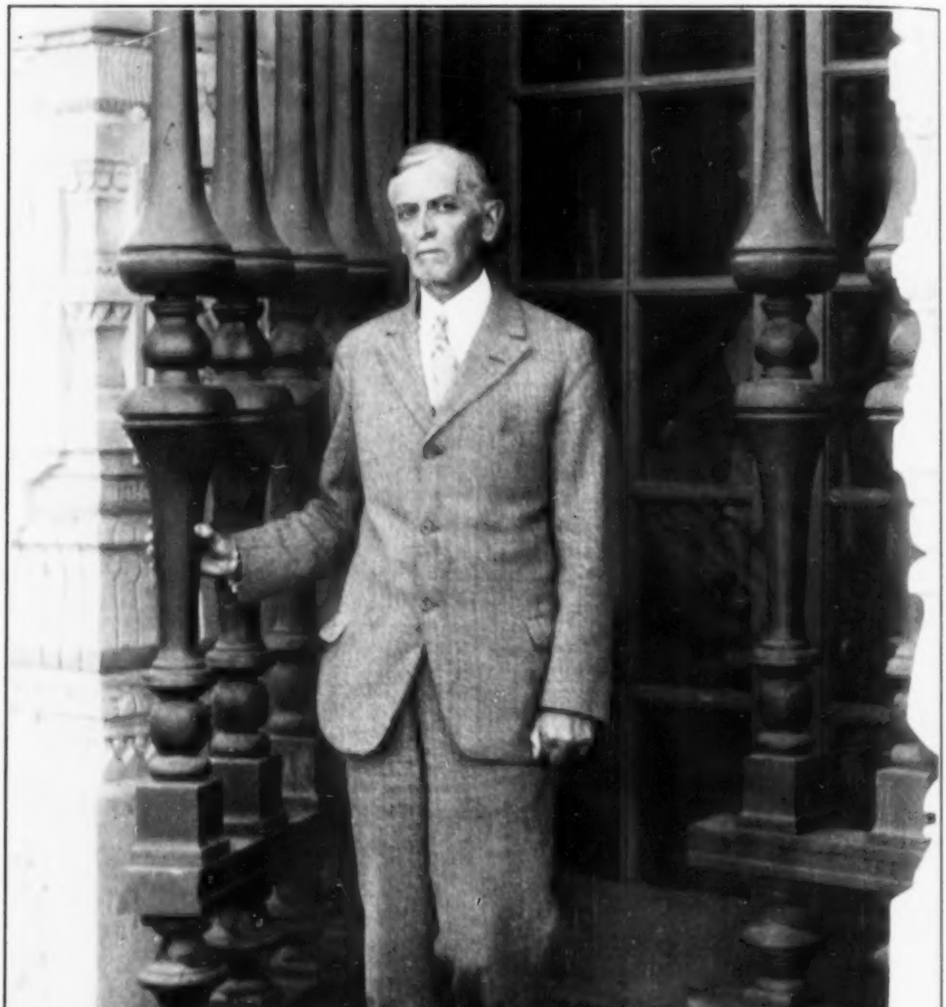
At the dedication exercises of the Crellin Laboratory, addresses were made by Dr. Robert A. Millikan, chairman of the executive committee of the California Institute of Technology, and by Dr. Linus Pauling, director of the Gates and Crellin Laboratories. Dr. Millikan spoke on the development of chemistry at the institute. Of its early years he said:

In the spring of 1916 all of us scientific ground squirrels, who all over the United States come up occasionally to sun ourselves at the tops of the holes in which we are burrowing, found the news spreading from hole to hole that a new laboratory of physical chemistry was being started at Pasadena, and that this laboratory was to be under the direction of Arthur A. Noyes, who henceforth expected to oscillate between Boston and Pasadena.

The prestige of Dr. Noyes's name was what gave this news particular interest and currency, for the Institute of Physical Chemistry which Dr. Noyes had founded and directed at the Massachusetts Institute of Technology had already become, through his own work and that of the group of brilliant young men who had

George D. Haight

THE CRELLIN LABORATORY OF CHEMISTRY



ARTHUR AMOS NOYES

AT THE ENTRANCE OF THE GATES LABORATORY OF CHEMISTRY, OF WHICH HE WAS DIRECTOR FROM ITS FOUNDATION IN 1916 UNTIL HIS DEATH IN 1936.

DR. LINUS PAULING
PROFESSOR OF CHEMISTRY, DIRECTOR OF THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY.

come out of it, the most outstanding laboratory of its kind in the country. Indeed, Dr. Noyes himself was already regarded as the most influential of the founders and inspirers of physical chemistry in the United States.

Within a few months of this time Dr. Noyes, whom I had never met before, and his old-time M. I. T. friend, Dr. Hale, whom I had known well since 1896, came to my door in the Ryerson Laboratory of Physics at the University of Chicago saying they wanted to talk over plans and discuss possible personnel for the new "Gates Chemical Laboratory." I first saw this laboratory in January, 1917, when I stopped here for a week to give a few lectures in Throop Hall on my way back to Chicago from Berkeley, where I had been giving the so-called Hitchcock lectures. Let me describe what I saw then. Just two buildings on this campus, namely, Throop Hall and the Gates Chemical Laboratory, the rest weeds and dead or dying orange trees. Thirty-seven students all told had up to that date, January, 1917, taken the bachelor's degree from this institution, which in 1908 had announced to the world that it proposed to cease to be essentially a manual training high school and become one of the outstanding scientific and engineering schools of the country.

I marvelled then and I marvel now at the intrepidity, as well as the faith and the vision of the men who, led by George Ellery Hale, took the responsibility of making such an announcement. There was not a hundred thousand dollars of endowment in sight when they made it.

By 1917 there were a few of them who had stepped up and backed up their words with enough of their own funds to provide some small beginnings of advanced educational facilities. Mr. Arthur H. Fleming and his daughter, Marjorie, had bought the present campus, and with the aid of other public-spirited citizens had provided for the cost of Throop Hall, erected in 1910.

The first provision for advanced work in chemistry or any other science was made six years later in 1916, when the brothers Charles and Peter Gates came forward and built the first wing of the Gates Chemical Laboratory and Marjorie Fleming provided a fund for research in chemistry. All honor to these pioneers, who ventured before there was any assurance of success. Ninety-five per cent. of all business ventures fail, and I suspect the record of philanthropic enterprises is not much better. The "*enterprisers*"—the men who start things off *and make them go*—richly deserve all the credits and all the social rewards which they ever get. Thus chemistry, through the Gates brothers, made its start at the California Institute of Technology.

EARL BALDWIN McKINLEY

EARL BALDWIN MCKINLEY, dean of the medical school, professor of bacteriology and director of medical research, George Washington University, was one of the six passengers aboard the Hawaii Clipper which apparently plunged into the Pacific Ocean at one of its deepest points on July 28, 1938.

Earl McKinley was born at Emporia, Kansas, on September 28, 1894. He entered the University of Michigan on the combined curriculum in letters and medicine, receiving the baccalaureate degree in 1916. The world war interrupted his work in the medical school; he entered the service on May 7, 1917, and was discharged on August 8, 1919, with the rank of first lieutenant, having seen action overseas in the Marne offensive of July and August, 1918. In September, 1919, he returned to the university completing the medical course in 1922. During this period he served as an assistant in bacteriology as well as an instructor in physiological chemistry. In these capacities he came into direct contact with Dr. Novy, whose stimulating influence he frequently acknowledged and whose advice and aid he constantly sought.

Shortly after completing the required program of study in medicine and before entering on an internship for which he had qualified, Dr. McKinley was appointed assistant professor of bacteriology and pathology at Baylor University, Dallas, Texas. While there he had occasion to investigate a number of disorders, especially bacillary dysentery. These experiences crystallized his thoughts and he realized his interests were in research rather than the practice of medicine; therefore, in the spring of 1924, although his accomplishments had been rewarded by advancement in rank, he applied for and was granted a National Research Council fellowship in the medical sciences for study abroad. A year was spent with Professor Bordet at the Pasteur Institute in Brussels. This contact with foreign workers was of inestimable value and revealed that medical problems know no international boundaries.

While residing in Belgium he accepted an appointment as assistant professor of bacteriology in the College of Physicians and Surgeons of Columbia University, returning to New York in the fall of 1925 to assume his duties. For two years he shouldered his full share of the regular instructing load and in addition, attempted to unravel the mysteries of a number of diseases such as poliomyelitis and lethargica encephalitis. An inherent faculty for organizing and administration led to his selection in the establishment of the division of bacteriology when Columbia University founded the school of tropical medicine in Puerto Rico. It was during this activity that he became aware of the paucity of knowledge regarding diseases seemingly indigenous to the tropics and the importance these diseases might assume as world problems with the development of aviation.

THE LATE DR. EARL BALDWIN McKINLEY
DEAN OF THE MEDICAL SCHOOL, PROFESSOR OF BACTERIOLOGY AND DIRECTOR OF MEDICAL RESEARCH, GEORGE WASHINGTON UNIVERSITY.

Accordingly he relinquished his connections in New York and arrived in Manila early in June, 1927, to take the position as field director with the International Health Division of the Rockefeller Foundation. He was charged with the duty of reorganizing the public health laboratory service in the Bureau of Science cooperating with the Department of Health of the Insular Government. This assignment was satisfactorily consummated within the year and he found time to assemble the data for and write a monograph entitled "Filterable Viruses and Rickettsia Diseases." Having accomplished the task for which he was originally sent to the islands and fearful lest the projected plans of the foundation would entail him in endless administrative details and thus submerge opportunities for experimentation, he was quite willing to rejoin his old department at Columbia when the call came in the spring of '28. The appointment was that of professor of bacteriology and director of the school of tropical medicine of the University of Puerto Rico. He took up his duties in San Juan shortly after the island had experienced one of its most devastating tornadoes, where he had the unusual opportunity of observing at first hand many tropical diseases modified by exposure and famine. For three years he devoted himself unsparingly to the development of the school and hospital. In the winter of 1931, in collaboration with the writer, studies on leprosy were begun. Attempts were made to cultivate the causative agent of the disease and to transmit the malady to laboratory animals. The results of these experiments were published, and in 1937 Dr. McKinley spent his sabbatical leave in the Philippines confirming and extending these investigations. He had with him on the flying boat a number of specially prepared substances which were to be used in the skin-testing of patients with leprosy in Manila.

In September, 1931, he accepted the deanship of the medical school of George Washington University and took up his residence in Washington. In this new environment, the prodigious energy of the man was unleashed. He was a born leader and in the capital the multiplicity of scientific organizations with which he promptly affiliated responded to the stimulus of his personality. His keen, active, versatile mind disclosed an eagerness to share his experiences; he seemed to know every one connected in any way with the medical sciences. He was especially active in the American Leprosy Foundation and in the Academy and the Foundation for Tropical Medicine. As a member of the executive committee of the American Association for the Advancement of Science, he gave unstintingly of his time, and his contributions to the work of the association were significant and far-reaching. He was on the editorial committee of *Science* and was to have become in the autumn one of the editors of THE SCIENTIFIC MONTHLY.

One might conclude that the diversification of interest would preclude active participation in research, but such was not the case. He continued his investigations of tropical diseases. Under the sponsorship of the National Research Council he conducted a survey of tropical medicine, spending much time abroad in the gathering of the data. On the disastrous voyage he was extending this study by taking samples of the microbic content of the air at various points over the Pacific, in an effort to unravel the enigma of the transoceanic spread of disease. His untimely disappearance just as he was equipped for still finer things has removed prematurely a worker who was associated in a very significant fashion with an unusually large number of activities. His death is a tragedy for his friends, and science is prematurely deprived of one who had much to give.

MALCOLM H. SOULE